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PETROLOGY OF THE ALKALI-GRANITES AND PORPHYRIES OF QUINCY AND THE BLUE HILLS, MASS., U. S. A.

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WITH TWO PLATES.

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Part I.

The most prominent topographic feature in Eastern Massachusetts is the range of hills, known as the Blue Hills, lying a few miles south and southeast of Boston, chiefly in the towns of Quincy and Milton. The range, which forms the southern rim of what is known as the Boston Basin, begins on the west in a beautifully rounded hill, The

Great Blue Hill, with an altitude of about 600 feet (200 meters) and extends with gradually diminishing elevations, in an easterly direction, with a gentle bow to the south, as a series of rounded hills which die out as the shores of Quincy and Hingham bays are approached.

The Blue Hills proper, or that portion which lies between the Great Blue Hill and the last prominent hills near West Quincy, now form a public park, the Blue Hills Reservation, which ranks as one of the most beautiful parks in the neighborhood of any large city. Although traversed by convenient roads and foot-paths, the natural wild and wooded character of the hills has been perfectly preserved. From the higher points pleasing and extensive panoramas of the surrounding country may be seen on the north south and west, while to the east and northeast, the ocean and its numerous bays form a distant background in a view of great beauty.

With the exception of relatively small areas of Cambrian slate and a few diabase dikes, the abundant rock exposures over this area consist entirely of an alkali-hornblende-aegirite-granite or closely related porphyries, and it is with the petrology of these rocks that the present paper is concerned.

Previous work on the geology of the region.— In an extended memoir entitled "The Blue Hill Complex," Professor W. O. Crosby [1] has furnished us with a very detailed and valuable discussion of the geology of this area. His description of the rocks was essentially only a megascopic one, inasmuch as he had at his command comparatively little microscopic or chemical data, and that which he had appears to have been imperfect and to some extent misleading. Up to the present time the only petrographic work which has appeared describing the rocks are:—brief notes descriptive of the granite by G. N. Hawes [2], M. E. Wadsworth,[3] G. P. Merrill;[4] an imperfect description of the granite and porphyries, by Dr. T. G. White [5]; a brief description of the Quincy granite accompanied by an excellent analysis by H. S. Washington [6]; and a rather detailed description of the granite from the more important quarries of the Quincy district by T. Nelson Dale.[7] The last mentioned paper contains, besides the descriptions

1 Occasional Papers, Boston Soc. Nat. Hist., **4**, 19, (1895).
2 Tenth Census U. S., **10**, p. 18.
3 Descriptive Cat. of American & Foreign Rocks, Boston, No. 71 (1883).
4 Building and Ornamental Stones. Report U. S. Nat. Mus., p. 409 (1886).
5 Notes on the petrography of the Boston Basin. Boston Soc. Nat. Hist. **28**, No. 6 (1897).
6 American Journal of Science, **156**, p. 181 (1898).
7 Bull. No. 354, U. S. G. S. (1908).

of the granite from various quarries, quantitative estimates of the mineral composition as well as many interesting and valuable statements regarding the grain, joint structures, and other features relating to the economic aspects of the granite and quarries.

A recent paper by G. F. Loughlin [8] discusses the geology of the area particularly with reference to the probable relations of the intrusive rocks to the associated sedimentary formations.

The pegmatites occurring in two of the quarries on North Common Hill, Quincy, have been described together with their minerals by Charles Palache and the writer.[9]

During the earlier part of the writer's work on these rocks he had the assistance of Dr. J. D. Trueman who was at that time pursuing studies leading to the degree of Master of Science at the Massachusetts Institute of Technology, and whose recent lamentable death by drowning while working for the Canadian Geological Survey has deprived geology of one of its most promising and enthusiastic workers. The preliminary results obtained by Dr. Trueman were embodied in his Master's thesis and the writer wishes to acknowledge his indebtedness to Dr. Trueman for much careful and discerning field and laboratory work.

Almost the entire field has been gone over with great care by the writer in person, and in this task he has been greatly helped by the exceedingly full descriptions contained in Professor Crosby's memoir, and has had the further advantage of the latter's company on several field excursions and of his keen interest in the work throughout.

The author wishes here to express his thanks to the Metropolitan Park Commission for permission to collect specimens within the Blue Hill Reservation.

Summary of the geology of the area.— Those wishing to inform themselves regarding the general geologic features of the area are referred to the paper by G. F. Loughlin, previously mentioned, or in case more detailed information is desired, the memoir of Professor Crosby should be consulted. It will be sufficient here to give only a very brief summary of the geology.

The alkaline rock series, as it may be called, occupies a roughly elliptical area having a nearly east-west major axis of about 9 miles (15 km.) in length, and a minor axis of from two to three miles (3 to 5 km.). Its eastern end lies near the Weymouth-Fore river.

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[8] American Journal of Science, **32**, (July, 1911).
[9] These Proceedings, **47**, No. 4 (July, 1911).

Thence it extends to its abrupt termination at the Neponset Valley along the western base of the Great Blue Hill. The Fore River as well as the Neponset Valley probably mark great north and south faults. On the north, along a line crossing northern Quincy and southern Milton, the alkaline rocks are bounded by an east-west fault contact with the carboniferous sediments of the Boston Basin. At the eastern end on the southern side, in northern Weymouth, the alkaline rocks are probably in fault contact (not actually exposed) with an essentially sub-alkaline granite, then for a short distance in fault contact with Cambrian slates or granite through northern Braintree. Further west they are in conformable contact with the coarse (basal) carboniferous conglomerate of the Norfolk Basin. On all sides, then, the boundaries are practically great major faults, and the alkaline rocks comprise essentially a great fault block, or more correctly two, an eastern and western member, and these appear to have been elevated, particularly the western and larger block, which was also tilted up at the north more sharply than the eastern member.[10] The eastern block is crossed by numerous minor, chiefly north and south, faults. These as well as the major boundary faults, and their dissection of the area, have been most fully and carefully worked out and described by Crosby.

The alkaline rocks are intrusive into Cambrian (certainly as late as middle Cambrian) sediments, consisting essentially of slate with quartzitic and limy bands. They are certainly earlier than the adjoining sediments in the Norfolk Basin, an arm of the Narragansett Basin, which are carboniferous, but at present their exact age cannot be stated. In the immediate neighborhood of the granite, the slates have been indurated and somewhat metamorphosed, but extreme metamorphism is not, it is important to note, a characteristic of such of the sediments as now remain.

Although all of the rocks of the series were undoubtedly intruded during a single great period of intrusion, one member, the aporhyolite, has been held by Crosby to be the youngest of the alkaline-rocks. As will be shown beyond, there is reason to believe that it was earlier than the other rocks of the series.

With the exception of the large number of small dikelets of microgranite that are found cutting the slate at the contacts, and of which Professor Crosby has given us a very detailed description, of the dikes of granite cutting the slate in the Pine Tree Brook Reservation and

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10 See Crosby, loc. cit., p. 534 et seq.

the porphyry in the region about Chickatawbut Hill, of one or two narrow, fine grained granitic stringers cutting the granite elsewhere near its contact or passage into the contact porphyry, and of the small dikes of pegmatite found at one or two points in the area (also near the porphyry cover), dikes, genetically connected with the alkaline magma, are conspicuous by their absence. The complementary dikes formed by differentiation, which are so prominent a characteristic of many intrusions of alkaline rocks, are here entirely absent. This peculiarity is believed to be due in part, as will be pointed out later, to the chemical composition of the magma, and in part to the consolidation of the magma relatively near the surface.

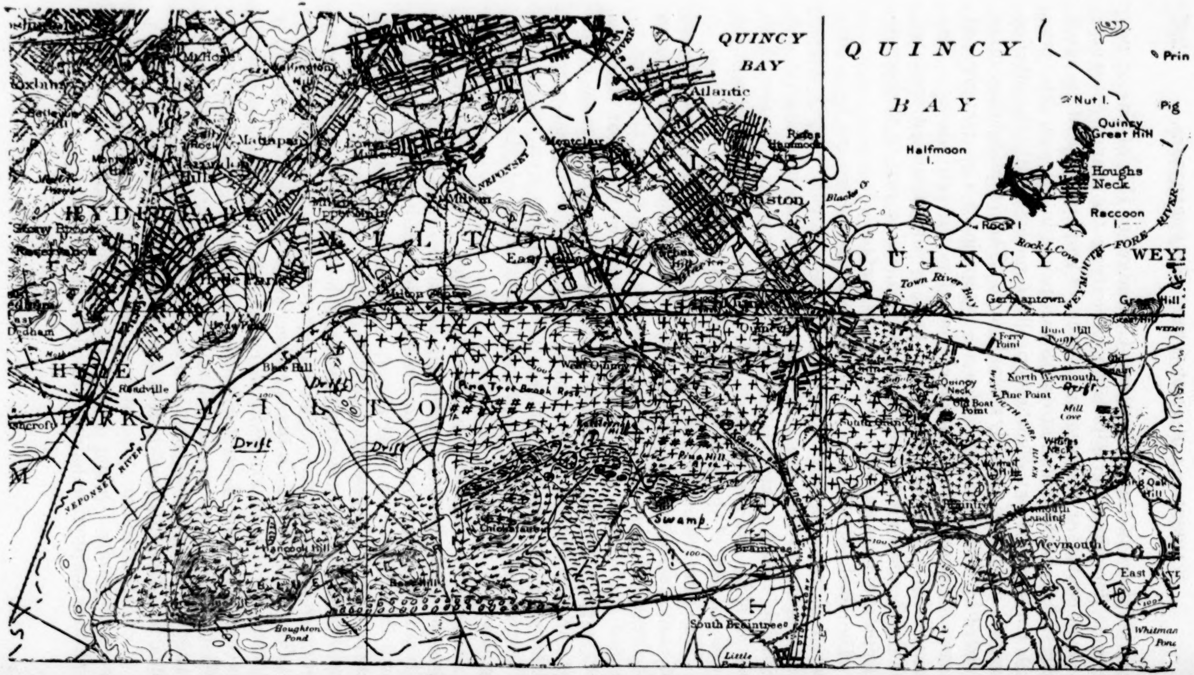
The alkaline rocks as well as the slates have been cut by a later series of basic dikes. These are for the most part heavily altered but appear to have been all essentially diabasic in character and certainly bear no near relation to the alkaline rocks. Neither these nor an older, pre-granitic series of trap dikes cutting the slates in the northern part of the area will be described here.

The entire area, like all of Eastern Massachusetts, has been exposed to erosion since the close of the Appalachian revolution. This erosion has removed all of the carboniferous strata and nearly all of the invaded cambrian or older sediments, together with a great thickness of the upper portions of the alkaline rocks, particularly over the northern and once more elevated part. Much of the original porphyry cover over the southern and western part of the area remains and these rocks now make up practically the whole of the Blue Hills proper.

Besides its alkaline character, somewhat peculiar chemical and mineralogical characters, a leading characteristic of this intrusion is that it consolidated under conditions which resulted in the formation of a thick protecting cover of porphyritic or even glassy rocks, which differ from those beneath chiefly in texture: differentiation did not take place to any great extent and erosion has left the original igneous cover to a considerable extent unimpared for observation and study.

Rock Types. — The rocks of this series are all characterized by the presence of soda-potash feldspars either in the form of a homogeneous mixture (true mixed crystal?), cryptoperthite or microperthite: by the presence of either alkali-hornblends or pyroxenes or both, and, with the exception of one member, by the presence of abundant quartz. They may be divided into the following types: —

I — (a) Medium to coarse grained, riebeckite-aegirite-microperthite-granite (Quincy type): (b) the same, but with an inconspicuous porphyritic habit. (Rattlesnake Hill type.)



Scale about 1 inch = 1.5 miles.

II — Fine grained granite similar in mineral composition to I, but predominately riebeckitic and of a little more basic composition.

III — The Blue Hill Porphyries: riebeckite, aegrite bearing, quartz-feldspar or granite porphyries.

IV — Dark, alkali-feldspar- or rhombenporphyry.

V — Cognate Xenolithes occurring in I and III. These are for the most part fine grained varieties usually porphyritic and more basic than the granite.

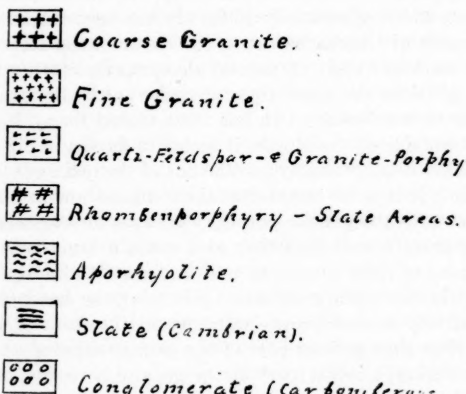
VI — Aporhyolite.

To these may be added, fine-granite and pegmatites, both of rare occurrence.

I.— The Coarse-Granite.

Distribution.— Reference to the map (No. I) will show that the granite, so far as its surface exposure is concerned, occupies somewhat less than one-half of the exposed area and if we assume that the extensive areas in the western section now covered with drift are underlain by granite, which is probably the case, then the porphyries

General map of the Quincy-Blue Hill Area. No. I.



This map is based on the regular Topographic map of the U. S. Geological Survey, the only available map of the area as a whole. Although not as good as could be desired it will serve to show the general location of the area in question and the approximate distribution of the principal rock types. To show their exact occurrence on a suitable scale would demand an expenditure of time and money that are prohibitive and would serve no very useful purpose.

and fine-granite would hardly cover over one-half of the batholith as at present exposed. The granite occupies a belt stretching across southern Milton on the north of the Blue Hills, comprises most of the rocks in Quincy and West Quincy, but is replaced by the fine-granite facies in eastern and southern Quincy and part of northern Weymouth. In fact the coarse-granite can hardly be said to occur in the Blue Hills proper except at one point (near Rattlesnake Hills), and in the form of dikes, cutting the porphyry cover, in the region just east of Chickatawbut Hill. As a matter of fact, its southern projections at Rattlesnake Hill and on Pine Hill, in both of which places it comes in contact with the porphyry, show a distinct tendency toward a porphyritic texture thus grading toward the porphyry.

Crosby states [11] that normal granite is transitional into "quartz porphyry and fine-granite" in the vicinity of Slide Notch. The writer has examined this section with extreme care and while unable to find any strictly normal granite having certainly the relations ascribed to it by Crosby, has found several well marked, granite dikes essentially of the Quincy type. One of these was first encountered about 75 ft. south of the extreme top of Chickatawbut Hill. It is here about 20 ft. wide, apparently nearly vertical in dip, and strikes about S. 60 E. and reaches a width of certainly 30 ft. It has been traced across the eastern member of Chickatawbut as far as the steep slopes of Slide Notch near its lower end. A second dike, nearly 50 ft. wide at one point, having about the same dip and strike as the first, outcrops at the entrance of the Notch. It has been traced for at least 400 ft. On the western side of the Notch, it seems to flatten in dip and there is also a smaller dike, probably an offshoot of the main one, a few feet to the south. It is to be noted that these dikes show in places along their contact with the granite-porphyry a slight development of very fine graphic-granite, and that they also contain numerous inclusions or segregations of dark porphyry and fine-granite exactly similar to those found in the main granite. Again near the head of Scamaug Notch, relatively coarse granite outcrops in the form of two dikes. While it is clear that at least part of the granite exposed at this point is a dike intrusion, another part of the granite here does not exhibit clearly marked contacts and is probably, as believed by Professor Crosby, an exposure of the underlying granite. The character of the granite-porphyry which seems to grade into the granite in one of its outcrops supports this view.

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[11] Op. cit., p. 366.

The contact relations of the granite and the associated rocks will be discussed later after these have been described.

The appearance and general characteristics of this granite are probably as well known as those of any rock in the country, owing to its wide use as a building and ornamental stone and to the descriptions already made of it by Dale and the other authors previously mentioned. In fact the present description is undertaken partly for the sake of bringing into one place the descriptions of all the alkaline rocks of the area, and partly for the purpose of adding certain mineralogical and chemical data of interest. No attempt will be made here to describe several minor variations in the granite due to local alteration. For these the paper by Dale should be consulted, as well as for many interesting details, relating to the rift, grain and joint structure of the granite.

Petrographic characters — Megascopic.— The normal type is a holocrystalline, coarse, equigranular rock (4 to 8 mm.); prevailingly gray— light to dark gray, bluish or greenish gray; where altered pinkish, reddish or purplish and greenish. The minerals are: — alkali feldspar, colors as above; quartz, clear glassy to dark smoky, less commonly bluish and opalescent; black, lustrous and beautifully cleavable hornblende in prominent, irregular spots, usually intergrown, particularly about the margins, with light to dark green aegirite; occasional separate grains of dark green aegirite; very rarely small purplish spots of fluorite and small brown zircon crystals. Occasionally the hornblende-aegirite spots which have suffered alteration are replaced by a soft brownish or yellowish clay-like material. The rock is remarkable for the beauty of its polished surfaces, particularly its darker varieties.

In places where the granite approaches the granite-porphyry, its marginal phase, the rock is not quite so coarse in grain and the equigranular texture gives place to a distinct but not prominent, granophyric one. (Rattlesnake Hill type.)

In the medium gray type of granite, which is by far the most abundant type, occur irregular and ill-defined darker streaks and cloud-like masses which grade more or less insensibly into the other. The darkest phase of the granite is known under the name of "black granite" and is the most highly prized variety from the commercial point of view. As will be pointed out later, these dark portions of the granite appear to owe their darker color to a greater abundance of the minute crystallizations of riebeckite and magnetite in the feldspars. While this difference may be due in small measure to slight differences in original composition, it is believed to result from a

deep-seated differential alteration of the granite mass. In the same way there are streaks and patches of much lighter color than the average. This phase shows many aegirite microliths in the feldspar but little riebeckite. In some of the quarries (Faulkner's, North Common Hill) a rather poorly defined zone of very light granite was observed on either side of a small quartz vein, and there appeared to be some connection between the vein and the whitening of the adjacent rock.

The pink and reddish granites (see later) are the result, for the most part, of surface oxidation of the iron content of the hornblende, etc. Along shear zones and in the neighborhood of trap dikes the granite has often a dark, greenish color due to the presence of streaks, disseminated scales and masses of some dull green, secondary mineral, probably chloritic, but whose composition has not been more closely investigated.

Microscopic.— The minerals observed in thin sections, are: an albite-microcline microperthite, quartz, soda-iron amphiboles, in part riebeckitic, in part cataphoritic, aegirite and sometimes a little of some closely related pyroxene; accessory minerals — aenigmatite, astrophyllite, zircon, titanite, iron oxide minerals, fluorite and very minor amounts of various alteration products.

The feldspar content of the rock is normally almost entirely a microperthite. Its grains are roughly equidimensional in cross-section; their elongation is in the direction of the edge 001/010. The outlines are always xenomorphic, except that occasionally in contact with the other minerals, particularly quartz, they show some development of crystal planes. It, nevertheless, clearly dominates the texture of the rock. The two members of the microperthite are very finely intergrown following the well known law for such intergrowths. The relative amounts of the two feldspars present in different grains is probably pretty uniform, although considerable apparent variations may be noted in the sections of different crystals and even in the same one. From point to point in a crystal there is undoubtedly considerable variation. The plagioclase member, as judged by its optical properties, is very near albite and this is borne out by the chemical evidence derived from the rock analyses. Its most probable composition appears to be $Ab_{98}\,An_2$ to $Ab_{95}\,An_5$. It is commonly, though not always, very finely twinned after the albite law. Locally in crystal sections where it predominates over the microcline, the twinning lamellae are broader and more uniform. A commonly noticed feature of the albite is its predominance about the ends and margin of the

crystal. It often extends out with the same orientation in the form of rather sharply bounded projections into the adjoining microperthite grains. When developed along the sides, it not infrequently sends out little prongs and hooks into the adjoining crystal much in the manner described by Prisson [12] for the albite in the perthite of the Red Hill, New Hampshire nephelite-syenite. The microcline member is twinned almost exclusively after the albite law only, and therefore, lacks the characteristic "gitter" structure usually associated with that mineral. The twinning lamellae are relatively shorter and broader than those of the albite member and their boundaries lack sharpness in most cases. The twinning in the microcline is not uniform, even in a single individual, and considerable portions may show little or no twinning. Its optical properties indicate that it is a nearly pure microcline and not a soda-rich variety. The intergrowth as it stands is apparently a mixture of nearly pure albite and potash feldspar.

A small amount of albite occurs in the rock in the form of separately crystallized grains occurring along the sides of the larger crystals, or in the interstices between them. There is often a suggestion, however, that many of these were originally continuous growths with the albite of the adjoining microperthite crystals, and that they have subsequently been deorientated by a slight movement in the mass.

The relations of the two feldspars detailed above is the normal relation seen without substantial variation in a great number of thin sections from the granites of the quarries. In the granite from various parts of the area and particularly from certain quarries, considerable variations from this texture, however, may be seen. The microperthite frequently contains random crystals of albite, often in considerable abundance. These are usually very small and have a slightly elongate, prismoid habit but do not possess sharp terminations. Again the microperthite may contain much larger, curiously irregular grains of albite, often including perthitically intergrown microcline. A number of these albites, much interdented along their contacts, may replace a good portion of an original feldspar crystal. Still again the microperthite may be replaced in part or almost entirely by aggregates of elongated, parallelly arranged, mutually interdented crystals of albite. Some potash feldspar may usually be noted intergrown with the albite. These crystals are often obviously arranged with their longer axes parallel to the original direction of perthitic intergrowth, but not always. They appear sometimes in the center of a micro-

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12 American Journal of Science, **23**, p. 272.

perthite crystal and again encroach on it from the margin. In many cases where the parallel groupings of albite cut across the original perthite strips, their direction of elongation and encroachment has been clearly determined by the structure of an adjoining microperthite grain. This may be in fact always the case, even when not apparent. This replacing feldspar may show simple albite twinning but much of it is untwinned. It is also practically free from the cavities and minute inclusions characteristic of the original perthite; secondary riebeckite and aegirite microliths are, however, quite common in it. In sections from certain portions of the granite in several localities, and particularly from the granite of Cashman's and the Gold Leaf Quarries, not only may all of the above described replacements of the microperthite be seen, but much of the original feldspar is seen to be replaced entirely by a very fine mosaic of feldspar grains among which albite seems to clearly predominate in amount. These mosaics are in part, at least, quite clearly the result of a granulation of the feldspar replacing the original microperthite, although probably the replacement and granulation were nearly or quite contemporaneous processes. All gradations from the normal microperthite crystal up to nearly or quite complete replacement and granulation may be easily traced. The process seems to be clearly one of recrystallization and albitization of the original feldspar which took place, either during the last stages of the solidification of the magma while the last liquids or gases were still very active, and before all movement in the crystallizing mass had ceased — a protoclastic structure —, or during some later recurrence of mineralizing activity and movement incident to a period of dynamic or igneous disturbance through which the region has passed. In either case there seems to have been a considerable increase in the relative amount of albite, at least locally. The first alternative as to origin appeals most strongly to the writer, especially when taken in connection with a closely similar change to be described later, as occurring in the feldspars of the associated porphyries.

With low magnifying powers the microperthite possesses a more or less dusty appearance and in the darker varieties of the granite, in rather thick sections, it is rendered almost opaque by reason of the very abundant, minute particles which are scattered through it. These included particles are: — 1st.— microliths of soda-hornblende, and aegirite; 2nd — exceedingly minute black specks and crystals (iron oxides); 3rd — minute indeterminate particles and cavities, the latter often more or less filled with brownish or black material.

The total amount of these particles varies widely in different specimens, in different feldspars in the same rock and even in the same feldspar crystal. It may be said, however, that they are most abundant in the granite having a darker color and are undoubtedly largely responsible for that color. The hornblende and aegirite microliths occur together in varying proportions, or one may occur almost to the exclusion of the other. No regularity can be discovered in this variation. The microliths of both show a tendency to an arrangement parallel to the direction of perthite intergrowth, to the direction of the albite twinning plane, and to the cleavage directions. They also occur commonly quite at random. The hornblendes are chiefly of a deep blue color — riebeckitic — although in sections, showing the green, cataphoric variety of hornblende in larger crystals, the microliths have also a corresponding deep-green color. Their habit is either that of short prismoid grains or more commonly of much elongated prisms or even hair-like growths. They sometimes form radiating clusters. The great majority are very minute and the largest rarely exceed 0.02 mm. in breadth or length except the more hair-like forms which attain a greater length. The aegirite microliths vary from the most minute particles up to ones 0.01 or 0.02 mm. in their greatest dimension, which is ordinarily the direction of the vertical axis. They commonly show a curious tendency to arrange themselves end to end, with minute swellings and irregularities along their sides. In color they are pale yellowish green or yellow to almost colorless. α is always nearly parallel to the vertical elongation as it should be in aegirite, a characteristic which obviously excludes their being epidote, a mineral they resemble in general appearance and which they have apparently been mistaken for by Dale. The minute black specks and grains, presumably iron oxides, the indeterminate particles, probably sericitic material or kaolin, and the cavities, show a great preference for the microcline member of the microperthite in which they are astonishingly abundant. It has been frequently noted in feldspars in which the black particles, etc., are more than usually plentiful, that they are concentrated a short distance on either side of cleavage cracks now healed with fresh albite material, also about the later albite crystallizations mentioned above, but never in them. The cavities seldom exceed a few thousandths of a millimeter in their greatest dimension. They are round, ellipsoidal or irregular in form, and with the exception of a little brownish black or reddish material appear to have no filling. Although one doubtless gets a somewhat exaggerated idea of their total bulk from micro-

scopic study, it is difficult to escape the thought that they must affect somewhat the density of the rock, and they must certainly render it more susceptible to the action of chemical alteration.

The quartz is throughout highly xenomorphic in its outlines. The undulatory and broken extinction in most of its grains show that all of it has been subjected to strain. Much of it, particularly in sections which show granulation and secondary recrystallization of the microperthite, is broken and in extreme cases (granite from the Gold-Leaf quarry) it has been reduced to a mosaic of small grains. All of the quartz contains abundant cavities, the majority of the large ones containing liquid with a movable bubble. They are usually arranged in gently curving lines across the quartz and in many cases obviously mark the direction of an old resealed fracture.[13] Minute particles of iron oxides are closely associated with the cavities. The quartz also includes rather rarely small riebeckites, but this is generally, if not always, along fractured or broken zones. The quartz commonly includes, and is intergrown with, aegirite; the same is also true of zircon, although the latter is of course much less abundant than the aegirite.

The hornblende, always with more or less aegirite, forms irregular patches of approximately the same area as the feldspar grains. Two or more crystals are often grouped together. Its crystals are usually broad with a tendency toward prismatic elongation. Toward the quartz it often develops its prism zone, but these are marked by many projecting points and irregularities. Although it often penetrates the borders of feldspar it is also found wrapped about the end of the microperthite grains, and seems generally to have been controlled as to its external form by the more abundant and dominant mineral. Along its prism zone where seen in contact with feldspar and quartz it shows a highly ragged contact surface. Even when low magnifying powers show a fairly well marked line, higher powers resolve the contact surface into a series of irregular projections and indentations. The hornblende is often separated to a greater or less extent from the other minerals by a growth of aegirite. Although the aegirite seems to have attached itself occasionally to an original crystal surface of the hornblende, it is usually found interpenetrated with the latter, the vertical axes of the two being parallel. Outwardly the aegirite develops to the exclusion of the hornblende, particularly

[13] Compare with description of the pegmatite quartz where more details are given. Warren and Palache, These Proceedings, **47**, No. 4, (July, 1911).

about the ends where it is usually seen in greatest abundance. Although the marginal aegirite may form a continuous mass about the hornblende, it more often consists of a number or many individual crystals which may be parallel, slightly divergent, or subradiate in arrangement, and these project out into the feldspar or quartz most irregularly and are often accompanied by numerous semi- or wholly detached particles. It is also not at all uncommon to find inclusions of aegirite lying unorientated in the hornblende. While these latter favor the margins they often lie well within the hornblende substance. Many of the original hornblende grains have evidently been broken apart before crystallization had ceased in the magma, for the separated parts of what was once obviously a continuous crystal may be seen with its broken ends margined with aegirite exactly in the same manner as the natural ends. It is not unusual to find a hornblende grain accompanied by a development of hornblende prisms, sometimes with a divergent arrangement, which project out unto the adjoining minerals: again the hornblende area may consist of a mass of prismoid crystals more or less grouped and of various orientations accompanied by other materials — grains of iron oxide (chiefly magnetite) titanite, calcite, granular feldspar and even fluorite. Such groups appear to be in large part at least recrystallizations. In such cases the aegirite originally present seems to have suffered little or no change. This hornblende is always of the deep blue type (riebeckitic). The minerals mentioned as accompanying the secondary hornblende can be seen to follow in the arrangement of their grains, to some extent at least, the structure of the original mineral. Perhaps the titanite is the only one of these calling for any special notice. Where present its amount may vary from very little to an amount that, in extreme cases, may constitute perhaps one fifth of the whole area. It consists of grains or aggregates of grains whose outward form seems determined by the structure of the original hornblende, or of those minerals which developed simultaneously with it. It thus lacks entirely the habit usually associated with titanite. Its optical properties serve, however, to prove its identity. It seems to be secondary and doubtless derived its titanium from the titantium content of the original hornblende, or in cases where the amount of titanite appears to have been much too large for the amount of titanium present in the hornblende (probably not in excess of 1.5%; see anal. of hornblende from pegmatite — Warren and Palache, loc. cit., p. 124), from included aenigmatite or ilmenite. The lime cannot have come from the hornblende and the presence of calcite with the titanite is suggestive that

this constituent was introduced from outside. In fact these areas seem to represent a phase in the alteration of the original hornblende which gave rise to secondary riebeckite accompanied by magnetite and other minerals, in part introduced from the surrounding rock, among these titanite, in cases where the amount of titanium was adequate. In this connection it is interesting to note that titanite having somewhat similar characteristics and accompanied by chlorite and calcite, has been observed by Pirsson and Washington as a secondary mineral replacing hornblende (basaltic) in the fine grained camptonites from the Belknap Mountains of New Hampshire.[14]

These altered hornblendes have doubtless given rise to the small pits and yellowish decayed spots seen megascopically in the finished surfaces of the quarry granites.

The inclusions in the hornblende in addition to the aegirite are: fluorite, in minute, usually anhedral grains; black oxide specks and grains, probably magnetite, scattered for the most part, but also arranged in curiously curved strings or bands, usually traversing only parts of the crystal and then commonly on one side or about a portion of the margin; larger, black grains of iron oxide; and a dark red mineral, probably aenigmatite (see beyond).

It is probably safe to say that the predominating hornblende is a riebeckite. This is certainly true of the granite in the eastern part of the quarry district (North Common Hill and eastward in Quincy). In many slides from the granite of this district it is the only variety of hornblende present. In the West Quincy district and westward in Milton the riebeckite is in considerable part replaced by a hornblende which is apparently a cataphorite or a closely related variety. In many sections this variety is seemingly the only original hornblende present, although it is difficult or impossible in random sections to distinguish always surely between the two. What is here called riebeckite has substantially the same optical properties as those given for the hornblende of the pegmatites previously described by the writer and C. Palache.[15] These are: — $\alpha \wedge c' 4°$ to $5°$; Axial plane perpendicular to b, (010); Opt.—, Bisectrix acute = α; Axial angle medium to large. Dispersion strong, giving rise to colored axial bars (red and blue). Double refraction very low: pleochrism with low or medium magnifying powers: α, deep-blue to smoky-blue or green; γ, very dark, smoky-green to almost black; β, pale yellow or slightly

14 American Journal of Science, **22**, p. 503 (Nov.–Dec., 1906).
15 loc. cit., pp. 152–3.

brownish often with a greenish shade. Absorption; $\gamma < \alpha > \beta$. Sections over 0.03 mm. in thickness are practically opaque for the deeper rays. Sections intermediate in position between the pinacoids often show peculiar dull, bluish-gray or drab tones difficult to describe. To the writer the most characteristic thing about the appearance of this hornblende is the color for the ray very near the vertical axis and the ray vibrating across the cleavage direction in (010) sections. With high powers it can generally be seen that the distribution of color for the α ray is not uniform. The strongest and purest blue appears in the outer parts of the crystal, along cleavage or other cracks, or in thin lamellae lying parallel to the c′ axis. The remainder of the crystal is green but assumes a bluish shade as the purer blue parts are approached. But very slight, if any, non-homogeneity can be detected for the other two rays.

The other variety of hornblende present, particularly in the granite from the western part of the granite area, where it appears to be nearly always relatively abundant sometimes almost to the exclusion of the blue type, seems to be closely related to the cataphorites of Brögger and particularly to the sodic hornblende described by Pirsson [16] as occurring in the nephelite syenite of Red Hill, New Hampshire. The pleochrism is strong and somewhat variable: α, light yellow-brown often with a greenish tint; β, dull green to almost black; γ, deep olive-green or less commonly olive-brown. The absorption is very strong, $\beta > \gamma > \alpha$. The angle, $\gamma \wedge c'$ is large and is variable even in crystallographically continuous crystals. This angle has been observed to vary in a single grain from 20° to 32°, and these figures represent variations commonly observed in the run of sections, although extinctions as high as 37° have been noted. The variation in the extinction angle is accompanied by a more or less marked variation in the color of the ray. While in some sections the change is marked by a fairly well defined zonal structure, the variations are often distributed over ill defined areas and are often distinctly gradational. Distinct crystals of the blue and green hornblendes seem to occur in the same rock, but the two are commonly grown together in parallel position (except in cases where the riebeckite is clearly secondary) the riebeckitic or blue type being developed marginally. The general mode of occurrence of the riebeckitic type in the granite and its presence alone in the pegmatitic facies of the granite, seem to point to the conclusion that it is the variety which develops when pneu-

16 American Journal of Science, **23**, p. 268 (1907).

matolytic agents are active. That such agents, particularly water or water vapor, are of prime importance in its formation is also borne out by its occurrence as a secondary product from the alteration of the original hornblende as noted above. Indeed, the development of the very closely related, or perhaps almost identical, crocidolitic amphibole found in the cavities in the pegmatite pipes and along joint surfaces in the granite, indicate that its solution and recrystallization may be carried out under conditions considerably removed from those prevailing during magmatic period. In this connection it is perhaps worth suggesting that relatively small changes in the hydration of the molecules making up the hornblendes, and particularly in the amounts of ferro-ferri-silicate molecules brought about by the oxidizing or reducing effects of the pneumatolitic agents may cause disproportionally large changes in the colors of the various rays. The chemical composition of the hornblendes will be taken up when the chemical analyses of the rocks are considered.

The mode of occurrence of the aegirite has been in part described when speaking of its intergrowth with the hornblende. Its occurrence in the form of microliths in the feldspar has also been noted. The growths of aegirite are often so considerable that it predominates in amount over the hornblende. It is also found in the form of distinct grains which are most closely associated with the quartz with which there are occasional intergrowths. There was perhaps some tendency on the part of a portion of the aegirite to develop its prismatic zone toward quartz. Aegirite is, however, almost wholly anhedral and the contacts with other minerals are in general characterized by very irregular surfaces, projecting points, nubs, hooks, and by the presence of isolated or but slightly attached small particles, sometimes in considerable abundance. There is usually an elongation in the direction of the vertical axis. In many instances larger grains seem to have been broken apart and separated; again, a greatly elongated crystal or series of crystals end to end, may be seen extending along between the feldspar and quartz, or between two feldspars, or along fracture lines. Many aegirite patches, consist either of a relatively large crystal which contains elongated, prismatic crystals irregularly orientated and often with a subradial arrangement, or they consist wholly of an aggregate of variously placed prismatic crystals. It is also frequently noted that a number of small aegirites though not attached, form nevertheless what might be termed a community of grains. Zonal growths are not uncommon and indicate an earlier stage of development which is evidently connected in many cases, and

perhaps always, with an earlier formed pyroxene, remnants of which are occasionally to be seen within the aegirite. As a rule this earlier pyroxene is almost entirely altered or replaced and what remains is filled with inclusions of fluorite and ferruginous matter. It is almost invariably true that in grains which show this pyroxene, the remnants indicate that it was rounded in form, small in size, and that they are enclosed in or indent the feldspar. In sections of the somewhat less acid phase of the granite from near the porphyry contact on Rattlesnake Hill, grains of a nearly colorless to pale brown pyroxene having the general appearance of augite have been noted, surrounded by a well defined rim of aegirite with a very rapid transition between them. The exact nature of this pyroxene has not been made out. Its extinction γ on c' is 35° at least; its double-refraction seems to be lower than common augite. It is probably a calcium-iron-rich pyroxene similar to the pyroxene in the rhombenporphyry. Whatever its original character, it has in general suffered almost complete replacement by aegirite, probably during the later stages of the consolidation.

Occasionally a pyroxene of a deep-green color and otherwise showing substantially the properties ascribed to aegirite-augite occur. These appear to have preceded the purer aegirite but to have followed the other variety just referred to. They are thought from chemical considerations to belong to the aegirite-hedenbergite line of mixtures, probably near the aegirite end, although they may be aegirine-augite.

The aegirite or aegirine-hedenbergite of earlier formation, that is to say the better formed grains, which bear about their margins evidences of later growths of the aegirite (analogous to the growths on the hornblende) commonly contain quite abundant, often very abundant, inclusions. The later formed aegirite rarely contains them. These are, fluorite, in sharply bounded octahedra and rounded grains, sometimes of good size but usually minute, grading down to mere specks: opaque, black grains probably ilmenite; and rarely roundish minute grains of a deep red color, undoubtedly the same as the red mineral forming larger intergrowths with the aegirite and hornblende, and thought to be aenigmatite. (See later.)

The color of the aegirite in thin-section varies considerably and this variation is often seen in grains that are otherwise optically homogeneous crystals. The colors commonly observed are as follows: — α, pale to deep green, sometimes with a slight bluish tone: less commonly almost colorless (usually confined to one part of a grain). β, pale yellowish-green to almost colorless. γ, pale yellow to pale yellowish-green or almost colorless. In many crystals the whole or

part possesses a brownish-yellow or even a reddish-yellow color. This is often most pronounced about black oxide inclusions and is thought to be due to a pigment stain of ferruginous character. There at least appears to be no regularity about the distribution of these discolorations. The optical characters are otherwise the usual ones for aegirite.

In thin-sections from the quarries from the western half of the area a dark red mineral has been noted associated with the hornblende and aegirite. Its presence appears to have been first noted by Murgoci [17] who thought it to be a new mineral and tentatively suggested the name Quincyite for it. It appears to be of rather rare and somewhat irregular occurrence. Its crystals are for the most part small and its depth of color render them unfavorable for satisfactory study. So far as determined its properties are as follows: — cleavage-good, apparently prismatic, resembling that of hornblende; pleochrism-deep red or brownish to almost black for the ray making an angle of 30° to 40° with the cleavage; ray perpendicular to this, a bright mahogany-red. Double-refraction weak. The extinction angle is too large for any of the alkali amphiboles and the only mineral that seems to agree with these characteristics is aenigmatite. It is commonly, though not always, in parallel position with aegirite or hornblende and its contacts are usually rounded. It is also seen in the form of small, usually rounded grains sometimes enclosed in aegirite and also closely associated with masses of granular zircon. It has been noted also in close association with astrophyllite — apparently secondary after it — and on one instance it was noted largely replaced by this mineral. V. Hackman has described a secondary mineral having apparently properties very similar to, if not identical with astrophyllite, surrounding aenigmatite in the nephelite syenite from Umptek.[18]

Fluorite, as has been noted, occurs as included grains in the earlier aegirite and is often quite abundant there; it is also found, though less commonly, in the hornblende. Single grains or more often clusters or compact granular aggregates are sometimes seen associated with the quartz, and in such cases zircon and hematite are often present also. It has been noted that fluorite is apt to be more abundant in the granite where it is cut by small quartz veins. Zircon almost always is found in close association with quartz and rarely forms well

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17 Private correspondence.
18 Mikroskopische Physiographie, Rosenbusch, p. 384.

shaped crystals. The grains are rounded and are to a greater or less extent filled with a dusty, brownish material. It is sometimes intergrown with the quartz much after the manner described for the zircon of the pegmatites.[19] This occurrence of zircon as described appears to be a characteristic of riebeckite rocks (see Murgoci, op. cit.). Titanite has been already described occurring as a probable replacement of the hornblende. It also occurs to a small extent in the form of isolated grains scattered through the rock and commonly associated with ilmenite or magnetite. Ilmenite or magnetite, occur as included grains and more or less fine dust in all the minerals of the rock. While a little of it may be primary, the greater part of it is thought to be secondary even in the relatively fresh granite. Magnetite is more abundant as the alteration of the hornblende has preceded further, and is then noted in the form of well defined octahedra lying in or about the position of the original iron-bearing silicate. Hematite appears to a limited extent in the fresh granite as minute flakes or grains in the feldspar and with the aegirite. In some cases its presence is apparently connected with pneumatolytic processes, but in general it appears only in connection with more superficial alteration. It is abundant in red surface granites.

An interesting and more unusual accessory is the mineral astrophyllite. Attention has been directed to the occurrence of this rare mineral in the Quincy granite by Pirsson.[20] It is only very sparingly present and appears to be of irregular occurrence. It has already been described as occurring about and replacing the aenigmatite and the aegirite in which the latter was intergrown. It generally appears in, or attached to, aegirite or the hornblende, particularly when this is intergrown with aegirite. Pirsson also noted it intergrown with its cleavage direction parallel to the vertical axis of the riebeckite. The writer has also seen it attached to zircon and to grains of a not fully identified mineral, but one which suggested parasite in appearance. Its habit and properties according to Pirsson are: minute elongated laths grouped in bunches; cleavage, micaceous excellent; elongation parallel to c; A = b; B = c; C = a; strongly pleochroic; A, red orange, C, lemon-yellow; absorption, A>C; mean refractive index about, 1.7; extinction parallel to the cleavage cracks; birefringence

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19 Op. cit., p. 131.

20 American Journal of Science, **29**, p. 215 (March, 1910).
The writer is indebted to Professor Pirsson for an opportunity to examine the thin-section on which his observations were made. The mineral was more favorably developed for study in this than in any other which the writer has seen.

high 0.04. In convergent light a single biaxial optic axis was obtained on the edge of the field. According to the writer's observations the elongation is more likely parallel to ă than c′. It appears from its mode of occurrence to be a mineral formed by pneumatolytic processes.

Calcite is occasionally observed, sometimes filling small interspaces between the other mineral grains, again as small patches within the feldspar, and associated with titanite etc. in the altered hornblende groups. Associated with the calcite and titanite, also alone, grains of a mineral which seems to be siderite has been observed. This has been identified in some of the porphyries. Its presence is not surprising in a rock where iron is so abundant and lime almost lacking.

Special Variations of the Granite.— Four variations from the normal, gray granite may be specially noted. The first is that found at the Gold Leaf quarry already alluded to in the description of the recrystallization of the feldspar, p. (214), and the granulation of the quartz. Macroscopically the striking feature of this variation is the finely granular character of the quartz which is often stained reddish or yellowish with iron oxides. Besides these stains there are numerous red spots that appear in part to be due to an impregnation of small feldspar grains with iron oxide, and in part to the occurrence of distinct grains of some red mineral. Although very difficult to obtain satisfactory data regarding it, it seems to correspond closely to the aenigmatite and is so regarded.

The second variation is that found occurring as a rather sharply defined streak crossing the Ballou Quarry on North Common Hill. Its chief characteristic is its delicate purple shade of color. This is due to the very general distribution of minute scales and specks of hematite through the feldspar. The hornblende groups are nearly all heavily altered, being changed to a mass of riebeckite shreds, magnetite and hematite accompanied by a considerable amount of fluorite and calcite. The aegirite originally with the hornblende has been much less effected by the alteration. This streak appears to have been one in which pneumatolitic action was especially active. More or less of the same changes may be noted in the regular granite of the Ballou Quarry which on this account has been described by Dale[21] as a dark, slightly purplish granite.

The third variation is that known as the *pink* or *red type*. Its distribution is quite general. As clearly pointed out by Crosby[22]

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21 loc. cit., p. 100.
22 loc. cit., pp. 334–8.

it is a superficially altered and oxidized portion of the gray granite, and always passes gradually downward at no very great depths (estimated at 20 ft. in some places where particularly well exposed) into the normal gray type. The original dark silicates have been entirely destroyed, their places being occupied by abundant magnetite crystals, quartz and feldspar and calcite. The pink or red color is due to the presence of exceedingly minute hematite specks or scales resulting from the oxidation of the hornblende microliths originally contained in the feldspars, and in part also to a general distribution of ferruginous products through the rock.

The fourth, and perhaps the most interesting and important one, is that in which a rather indistinctly marked porphyritic texture is developed. This variation is found wherever the granite approaches the granite-porphyry of the contact zone. Its texture, although not strongly developed, is characteristic, and is due largely to the fact that a part of the feldspars are grown somewhat larger than the rest. This feature is well seen in the granite from the northern slopes of Rattlesnake Hill, on the Great Dome, and particularly over a large part of the Pine Hill area. In the latter location the passage of this phase of the granite into the granite-porphyry of the contact zone is perfect and gradual though always comparatively rapid. On the top of Rattlesnake Hill near the southern edge of the hill, this granite is found in a sharp but perfectly sealed contact with the porphyry. The same phenomena may also be observed elsewhere, and while we cannot doubt that the porphyry is in all cases but a more rapidly cooled phase of the magma, we are forced to conclude that the magma moved to some extent underneath its own cover forming sharp contacts with it.[23] It is to be noted that at such contacts, so far as observed by the writer, there is a more or less marked development, along the immediate contact line, of long, slender riebeckite prisms.

Under the microscope the minerals are seen to be essentially the same as in the normal granite. The texture is also much the same except that a part of the feldspar has attained a larger size and, that in portions of almost every section examined, areas will be found that

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23 It is not unlikely that this particular contact, which is steeply inclined, marks a lateral contact of a great dike which broke through or at least pushed up the porphyry cover at this point. "A few hundred feet to the west and a little to the north of the line of contact, rises a prominent knob of granite known as the "Rattle Rock." This rises to about the same elevation as the porphyry on Rattlesnake Hill and probably represents the exposed stump of a great dike or a cupola of granite which domed up or cut through the porphyry.

show the hornblende enclosing small feldspars and suggesting at once a close relation to the groundmass structures of the porphyry above. In the feldspar crystals, particularly the larger ones, distinct outlines, sometimes marked by the inclusion of small crystals of aegirite, of an inner zone of growth may be seen. This boundary marks the slight halt in the growth of the earlier formed crystals which is so clearly shown in the granite-porphyry as will be noted later.

Chemical Characters.— For chemical analysis a number of good sized fragments were broken from carefully selected samples of freshly quarried rock from the three localities listed below, one from well toward the eastern end of the Quarry section, one from $\frac{1}{4}$ of a mile west of the first and the third $\frac{1}{2}$ of a mile still further west, in the west Quincy district. A sample of the porphyritic phase of the granite from Rattlesnake Hill very near the granite-porphyry cover was also analyzed. Great care was exercised in avoiding xenoliths or parts that showed any discernible variation in grain. The percentages given are the average of closely agreeing duplicates, except that the values for ferrous-iron and alkalies are the average of three determinations each. The methods of analysis advocated by Hillebrand were strictly adhered to. The results are given on page 227.

For the convenience of those who have adopted the so-called "Quantitative Classification of Igneous rocks"[24] the "norm" has been calculated from the average of 1–2–3 given under 4.

	Norm.	
Quartz	32.10	$\frac{\text{Sal}}{\text{Fem}} = 16 > \frac{7}{1}$. Class I
Zircon	.30	
Orthoclase	27.24	93.70 Salic Minerals,
Albite	34.06	$\frac{Q}{F} = .52 < \frac{3}{5} > \frac{1}{7}$ order 4; quardofelic
Acmite	1.85	$\frac{K_2O + Na_2O}{CaO} > \frac{7}{1}$ = Rang 1; Peralkalic.
Diopside	1.21	
Magnetite	2.32	5.84 Femic Minerals
Ilmenite	.46	$\frac{K_2O}{Na_2O} = .75 < \frac{5}{3} > \frac{3}{5}$ = Subrang 3; Sodipotassic; Liparose.
	99.54	

The rock may, therefore, be termed a *grano-liparose* or more exactly an alkali-hornblende-aegirite grano-liparose. The calculation of the mineral composition of the granite can only be made approximately, since an accurate estimate of the amount of each mineral present

24 Quantitative Classification of Igneous Rocks, by Cross, Iddings, Pirsson, Washington, Univ. of Chicago Press, Chicago, Ill., 1903.

	1.	2.	3.	4. %	4. Molec. Ratio.	5.	6.	7.	8.	9.
SiO_2	75.08	75.58	73.93	74.86	1.247	72.97	71.65	68.54	78.49	71.34
Z_2O_2	.20	.20	(.20)[25]	.20		.20				
Al_2O_3	11.57	11.17	12.09	11.61	.114	12.13	13.04	15.47	9.99	13.97
Fe_2O_3	2.25	1.71	2.91	2.29	.014	2.77	2.79	2.03	1.94	1.95
FeO	.93	1.26	1.55	1.25	.017	1.09	1.80	2.09	1.18	1.00
MgO	.03	.04	.08	.05	.001	.20	tr	.21	.09	.62
MnO	tr	.05	tr	.02		tr	—	—	tr	tr
CaO[26]	.44	.49	.31	.41	.007	.74	tr	.30	.30	1.63
Na_2O	4.21	4.03	4.66	4.30	.069	4.61	6.30	5.68	3.74	4.84
K_2O	4.62	4.68	4.63	4.64	.049	4.79	3.98	5.75	3.84	3.89
H_2O—	.04	.10		.04		.10	1.11	.59	.72	.89
H_2O+	.19	.34	.41	.31		.35				
TiO_2	.20	.22	.18	.20	.003	.30	—	.14		.43
P_2O_5	tr	tr	tr	tr		.20	—	.10		
Total	99.76	99.87	100.95	100.18		100.25	100.67	100.90	100.29	100.56

Aver. Sp. G. 1, 2 & 3 = 2.661

1. Medium gray granite, Hitchcock Quarry, N. Common Hill, Quincy, Mass. Analyst, C. H. Warren.
2. Very dark granite, Reinhalter Quarry, West Quincy, from about 300 ft. below surface. Analyst, C. H. Warren.
3. Medium dark granite, Hardwick Quarry, N. Common Hill, Quincy, Mass. Analyst, H. S. Washington.
4. Average of 1, 2, and 3.
5. Slightly porphyritic phase from near contact with granite-porphyry. Quarry N. side of Rattlesnake Hill, Blue Hills, Reservation, Analyst, C. H. Warren.
6, 7 and **8** are taken from Rosenbusch's Elemente d. Gesteinslehre, 1910 Ed., p. 86, and are as follows:—

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[25] Assumed to be the same as in 1 and 2.
Fluorine though present in small amount was not estimated.
[26] From 0.1 to 0.28 or an average of 0.19% of this is present as $CaCO_3$, see Dale, loc. cit., p. 94.

6. Riebeckite granite. S. W. Houghnatten, Eftelöt, Sanelsvär, W. from Lougental, Southern Norway.
7. Riebeckite granite, Ekona — Sungale — Krater, Kamerum.
8. Riebeckite, Acmite Granite, Dahamis, Insel, Sokotra.
9. Arfvedsonite-Biotite granite,[27] Stony Brook Reservation, West Roxbury, Mass. Wm. F. Hall, Analyst.

cannot be made, nor if it could be done, could we apportion the various radicles of the soda-iron pyroxene and hornblende accurately as we do not know their exact composition. We may, however, proceed as follows and arrive at a mineral composition which will give us a close approximation to the relative amounts of quartz, the feldspars, the sodic-iron silicates, and the oxide minerals. The albite has been determined at least as sodic as $Ab_{95}\ An_5$ and possibly more so. Using this composition for the albite and making the assumption that magnetite is not present in an amount over one percent, which is certainly not far from the truth, further noting the fact that at least one third of the CaO is present as $CaCO_3$ and disregarding the slight excess of Al_2O_3 as being present in kaolin, we arrive at the following composition calculated to 100 percent. The water and fluorine have been also disregarded though they certainly enter into the hornblende present. The omission has the effect of making the hornblende figure somewhat low.

	Quartz	33.3
Microperthite	Albite $Ab_{95}An_5$	28.1
	Microcline	27.5
	Hornblende and Pyroxene	9.6
	Magnetite and Ilmenite Zircon	1.5
		100.00

Ratio, $\frac{\text{Feldspars}}{\text{Quartz}} = 1.67$

Ratio, $\frac{\text{Albite}}{\text{Microcline}} = 1.02$

Albite	50.5
Microcline	49.5
Microperthite	100.00

These percentages agree well with approximate measurements of the relative amounts of the constituent minerals made on thin-sections and with Dale's Rosival measurements [28] made on polished surfaces,

[27] F. Bascom, Journal Phil. Acad. of Nat. Sciences, **15**, 2d series, p. 135. (March, 1912).
[28] loc. cit., p.

the average of which are, quartz 30.6, feldspar 60.6, dark minerals 9.4.

The albite and microcline in the microperthite are almost exactly equal, which is also in agreement with crude microscopic estimates. The $Na_2 Fe_2 Si_4O_{12}$ (aegirite and corresponding hornblende) molecule predominates but the ferrous or ferro-ferri compounds are prominent, a fact to be expected from the known composition of the Riebeckite in the pegmatitic facies where these molecules exceed the $Na_2 Fe_2 Si_4O_{12}$.

Comparing the analyses of other Riebeckite granites given in columns 6, 7, and 8 with each other and with that of the Quincy granite, we note that all are characterized by exceedingly low MgO and CaO, by high iron content in both ferrous and ferric iron, and by high alkalies. The soda predominates, molecularly. With the exception of No. 6, in which the soda is greatly in excess, they show very nearly equal percentages of the two alkalies, though in view of the considerable variation in alumina this perhaps has little significance. An approximate calculation of the mineral composition of each is given below and shows a great variation in the relative percentages of the minerals which are in each case of essentially the same type.

	4a	6a	7a	8a
Quartz	33.3	20.6	12.0	41.4
Albite	28.1	47.2	47.1	30.4
Orthoclase	27.5	22.8	33.8	22.2
Pyroxene, Hornblende, Magnetite, Ilmenite, etc.	11.1	9.4	7.1	6.0
	100.0	100.0	100.0	100.0

Comparison of the three analyses of the Quincy granite with each other shows that there is some variation in the amounts of different oxides, and therefore, in the minerals. These variations were expected from facts revealed by the study of the thin-sections. Thus the granite of the Hitchcock quarry (1) was richer in aegirite and showed less of the riebeckite in the form of microclites scattered through the feldspar. The ferric-iron should therefore be relatively higher than in the dark granite from the Reinhalter quarry, in which is very abundant riebeckite (a hornblende rich in ferrous iron) both in large crystals and distributed through the feldspars. The samples came from localities separated by some distances and different elevations and are representative of the granite as a whole. Taken jointly

with the microscopic evidence the chemical analyses show conclusively that there is a small, but noteworthy variation in composition in the rock from different points, though such variations seem to be vicarious in character.

The granite from Rattlesnake Hill is a little lower in silica and higher in alkalies, thus leaning toward the granite-porphyry and fine-granite, (see beyond Nos. 10 and 13) but in the ferrous and ferric iron it is like the normal granite. It thus stands in an intermediate position chemically between the normal granite and its peripheral phases as it does texturally and in structural position.

The granite, No. 9, from the Stony Brook Reservation, West Roxbury, Mass., only a few miles distant (N. W.) from the area under discussion and described by Professor Bascom, differs from the Quincy granite chemically in higher lime, also in having lower silica; soda predominates over potash and there is much less total iron. Mineralogically the two are strongly contrasted, the Quincy is a microperthite granite, the Stony Brook granite, like an enormous preponderance of the granite of Eastern New England, is a two feldspar granite with a strong leaning toward monzonitic types. The former is characterized by soda-iron hornblendes and pyroxenes and never shows epidotic alteration; the latter is characteristically biotitic, perhaps carries an arfvedsonitic amphibole, and is epidotic. Though the Stony Brook granite is perhaps a nearer relative to the Quincy than some of the biotite granite of the Atlantic seaboard, they are still, mineralogically and chemically, sharply contrasted types.

Fine Granite.

It should be noted at the outset in describing this rock that the term "fine-granite" is here used in a more restricted sense than that in which it has been used by Professor Crosby. He used it to include a part of what is here termed "granite-porphyry" and he has also not distinguished between the fine-granite of the alkaline type and that associated in Weymouth with the biotite, subalkaline granite. Professor Crosby held that the fine-granite of the Blue Hills was an intermediate textural phase between the quartz or granite-porphyry and the coarser granite. With the possible exceptions of one or two points, there is no rock that can be properly termed fine-granite, having such relations. The phase of the granite-porphyry as the granite is approached is not readily recognized as a porphyry megascopically,

being quite granitic in appearance; nor did Dr. White's microscopic studies inform Professor Crosby as to the true nature of these rocks.

Distribution.— The exceedingly detailed and careful study of the relations of this rock to the coarse-granite and to the slates made by Professor Crosby has proved beyond doubt that it is throughout a contact phase of the granite magma. In the Quincy-Weymouth area (see general map, no. 1), viz. that part of the field lying roughly east of the line of the West Quincy Branch of the Railroad as far north as the West Quincy Station, in the area lying north and northwest of the Station in what has been termed the "Furnace Brook" area and also along the northern edge of the alkaline-rocks wherever the fine-granite is exposed as far west, at least, as Canton Avenue in Milton, this rock appears to be the only contact phase of the magma which was developed and this will be termed for convenience the Ruggles Creek type, since the most satisfactory exposures are found in the region about Ruggles Creek and from here the type specimens were chosen for analysis. The other exposures of the fine-granite, viz. in the Pine Hill area, Pine Tree Brook Reservation and in the area lying between Wampatuck and Fox Hill, all of which are comparatively small in contrast to the development of the rock in the Quincy-Weymouth area of the field, are closely associated with the other contact phases of the magma. The field exposures in these areas, particularly the first two, indicate that in places the fine-granite, often quite porphyritic, replaces the granite-porphyry etc. as the contact phase of the magma against the slate just as it does in the S. Quincy-Weymouth area and along the northern edge of the complex: at other points its relations are more obscure but suggest that there may be fine-granite zone intermediate between the rhombenporphyry and granite-porphyry and the granite. This is perhaps supported by the fact that in such occurrences the rock shows a much stronger porphyritic habit. Actual transitions to the porphyry and coarse granite have not, however, been observed with certainty although numerous sharp contacts have, and it is invaded by dikes of coarser granite just as the porphyry is. No certain contacts can be found for the mass lying between Wampatuck and Fox Hills but there is a strong indication that the fine-granite becomes more porphyritic in the neighborhood of the granite-porphyry and there may be a rapid transition into it.

Although actual contacts of the fine-granite with the slate in the Quincy-Weymouth area are apt to be concealed, enough are satisfactorily exposed to show that the rock is somewhat finer in grain at the immediate contact. Against those slate masses which represent

relatively deep projections into the invading magma, the width of the fine-granite zone is measured by a few feet. Where it marks the more elevated main contacts, its thickness is considerable. While it is not possible to estimate accurately what this thickness was in any case it was doubtless measured by tens of feet. Its contacts with the coarse-granite are exposed at several points and are usually, if not always, perfectly sealed but sharp in character. Professor Crosby believed [29] that these sharp contacts were due to differential movement of the still unconsolidated magma against its solidified margin, which was generally fractured and invaded by the granite magma as an incident to the process of intrusion. The facts in the field appear to support this reasonable hypothesis for there are numerous dikes of the coarse in the fine-granite and also inclusions of the fine in the coarse (see Crosby, op. cit., p. 352 et seq.). Professor Crosby has noted the occurrence of at least one contact where there appeared to be some gradation in texture, but in the writer's experience it can be said that the gradation is at most confined to a few inches (compare statements regarding the porphyry-granite contacts beyond).

It is to be noted especially that there are *no segregations* in the normal fine-granite, a point that will be taken up later in discussing the relations of the various phases.

The general distribution of the fine-granite is shown on the map. For a more detailed mapping of this rock and its relations to the slate and coarse-granite the special maps of Professor Crosby should be consulted.[30]

Megascopic.— This rock is a fine grained (one to two millimeters) slightly porphyritic one, of a prevailing light gray color though often light brown or pinkish from alteration. The phenocrysts are alkali-feldspar, are rather sparsely distributed and of characteristically elongated, rectangular outlines (1 by 3 mm. to 2 by 7 mm.). They are more abundant and conspicuous in some localities and become somewhat larger and more prominent in varieties that mark a probable gradation toward the granite-porphyry and probably also toward the slate contacts. Rarely rounded quartz phenocrysts occur, but these are wanting in the normal rock. Scattered quite plentifully

[29] op. cit., p. 355.

[30] It should be noted in this connection that a part of Crosby's fine-granite in northern Weymouth and Hingham is an entirely distinct rock from the fine-granite here considered. It belongs to the biotite, microcline-plagioclase granite which occupies extensive areas to the south and southeast of the alkaline rocks.

through the rock are minute black hornblendes averaging not far from a millimeter in cross section.

Microscopic.— The microscope shows that in the fine-granite of the Ruggles Creek type the minerals present are: — albite-microcline microperthite, quartz and riebeckite with accessory zircon, magnetite and ilmenite, fluorite, a little titanite, calcite, biotite, chlorite and limonite. The last three and a part anyway of the magnetite are secondary, and are present to only a small extent except in the heavily altered surface layer. In the fine-granite of the Pine Tree Brook reservation, we find in addition to the minerals above mentioned, aegirite, a green alkali pyroxene, occasionally small amounts of aenigmatite and rather more abundant fluorite.

The porphyritic texture noted megascopically is inconspicuous in thin section, for the reason that the feldspars are somewhat gradational in size and the larger grains are relatively so few that they are largely lost sight of. While the limits of size of the mineral grains lie between rather narrow limits, the texture of the rock may probably be best described as holocrystalline granular seriate. The feldspars are essentially identical in character and habit with those of the coarse-granite. The quartz is slightly less abundant and shows a tendency to micrographic intergrowth with the feldspar. In fact from some outcrops, probably near to the original contact with the slate, the graphic intergrowths are a prominent feature of the rock. The riebeckite is also essentially the same in habit and optical characters as in the coarse granite. In general it appears that in the fresh rock a green tone predominates over blue (except about the margins) for the ray (α) which is nearest the cleavage. The zircon is usually present in well formed crystals, which is in sharp contrast to the habit of this mineral in the coarse-granite. Aegirite, as has been noted, is present in the fine-granite from the relatively small outcrops on Pine Hill and in the Pine Tree Brook Reservation. Whether it was originally present in the mass northeast of Fox Hill cannot be told, on account of the extreme alteration of the dark minerals, but the general impression is that it was absent. This aegirite has the same relation as those described for the granite. In addition to the aegirite a deep green pyroxene closely resembling aegirite in general appearance but somewhat less pleochroic and of much lower double-refraction and with a larger extinction angle is present. This occurs either in separate, sub- to anhedral grains or is enclosed in the hornblende. It is often strongly altered to ferruginous material. It seems to be essentially the same pyroxene which appears sparingly in the coarse-granite and

in the granite-porphyry, and is thought to belong to the aegirite-hedenbergite line of pyroxenes. Magnetite or ilmenite is quite abundant in the form of inclusions in the hornblende. Its appearance suggests that it is secondary after some highly ferruginous mineral other than the pyroxene. Several grains of the dark red mineral, believed to be aenigmatite, have been noted enclosed in the hornblende, and the magnetite may be a replacement of this mineral. Fluorite in the form of included grains is often very abundant in the pyroxene, and it is also present, but somewhat less abundantly, in the hornblende.

Porphyritic Phase of the Fine-Granite.— The tendency of the fine-granite to become porphyritic where it probably grades into the typical granite-porphyry, and also probably for a very short distance where it is in original igneous contact with the slate, have been referred to. (The latter contacts are not satisfactorily exposed and the writer is not altogether certain on this point.) This type is best exposed for study in several outcrops in the Pine-Tree Brook Reservation and at one point just north of the entrance to Scaumaug Notch. The rock while not so profusely porphyritic as the granite-porphyry is still strongly porphyritic, showing abundant rectangular feldspars and rounded quartz grains. The groundmass is finer than the average grain of the typical fine-granite but is distinctly coarser than the groundmass of the granite-porphyry described beyond. The groundmass contains rather abundant "specky" hornblende. Microscopically the groundmass is essentially of the same texture as the fine-granite although it often shows, in the inclusion of the groundmass feldspar and quartz by the hornblende, an approach to the characteristic structures found in the typical granite-porphyry of the Blue Hills.

Chemical characters.— For chemical analysis a specimen of the fine-granite from an old quarry just south of Ruggles Creek, Quincy, was selected. Though stained slightly brown, the rock in thin-section seemed to be the freshest of any that could be obtained. The values are the average of duplicate analyses except that ferrous-iron and alkalies are the average of three and four determinations each.

	10.		4.	11.	12.
	Per cent.	Molec. Ratios.			
SiO_2	71.41	1.190	74.86	76.52	71.63
Z_2O_2	.10	.001	.20		
Al_2O_3	12.74	.125	11.61	12.30	13.71
Fe_2O_3	1.75	.011	2.29	.70	2.09
FeO	2.33	.032	1.25	.56	1.76
MnO	.10	.001	.02	tr	tr
MgO	.06	.001	.05	.16	.19
CaO[1]	.85	.014	.41	.31	1.31
Na_2O	4.59	.074	4.30	5.19	3.24
K_2O	5.00	.053	4.64	4.58	4.49
H_2O+	.56	(.028)	.31	.41	.51
H_2O-	.10		.04	.11	8
TiO_2	.38	.005	.20	.12	.34
P_2O_3	.22	.001	tr		tr
CO_2	.40		—		.41
	100.59		100.96	100.96	99.76

Sp. G. of No. 10 at 20° C. = 2.66

10. Fine-granite, South of Ruggles Creek, Quincy.
4. Average of three analyses of coarse Quincy Granite.
11. Fine-grained or Micro-granite — Neponset Valley, Mass., F. Bascom, Op. cit., p. 137, Intermediate in the field between the granite (No. 9) and the Aporhyolite (No. 12).
12. Aporhyolite. F. Bascom, Op. cit., p. 138, Peripheral phase of granite batholith, Neponset Valley.

The "norm" calculated from the above molecular ratios is as follows: —

Norm.		
Quartz	24.06	$\frac{\text{Sal}}{\text{Fem.}} = 1.14 > \frac{7}{1}$; Class I.
Zircon	.10	
Orthoclase	29.47	91.36 Salic Minerals.
Albite	37.73	$\frac{Q}{F} = .35 < \frac{3}{5} > \frac{1}{7}$; Order 4; quardofelic.

Norm.		
Acmite	.92	
Diopside	2.71	$\frac{K_2O + Na_2O}{CaO} = > \frac{1}{7}$ = Range 1; peralkalic.
Hypersthene	1.19	8.01 Femic Minerals.
Magnetite	2.09	
Ilmenite	.76	$\frac{K_2O}{Na_2O} = .73 < \frac{5}{3} > \frac{3}{5}$; Subrange 3; sodipotassic.
Apatite	.34	Liparose.
	99.37	

The rock is therefore a riebeckite-grano-liparose.

In calculating the mineral composition the albite was taken as $Ab_{95}An_5$, which is as near as it could be determined, and the total amount of feldspar was assumed to be that found by a careful Rosival measurement made on two thin-sections. The small amount of calcite and limonite were disregarded, but a part of the water above 110° was used in the proportion in which it was known to be present in the Riebeckite hornblende of the pegmatites [31] which optically appears to be identical with that in the fine-granite.

The results are as follows: —

Calculated.			Rosival Estimate.	Ratios.
Quartz	23.3	23.3	22.9	$\frac{\text{Feldspars}}{\text{Quartz}} = 2.84$
Albite $Ab_{95}An_5$	36.93	66.4	66.4	$\frac{\text{Albite}}{\text{Microcline}} = 1.25$
Microcline	29.47			
Hornblende	8.41	10.3	10.7	Albite = 55.6
Magnetite, Ilmenite	1.46			Microcline = 44.4
Zircon	.10			Microperthite = 100.00
Apatite	.34			
		100.00	100.00	

The percent of the molecules $Na_2Fe_2Si_4O_{12}$ and $(R'_2R'')_4Si_4O_{12}$ in the hornblende were found to be 44 and 56% respectively. In the pegmatite Riebeckite these were, 42 and 58%, which are in good agreement with those from the granite, and indicate the close similarity of the two hornblendes which was inferred from their optical characters.

Compared with the coarse-granite (4), we note 3.4% less silica; 1.1% more alumina; 0.5% higher total iron oxides, but with ferrous

31 Warren & Palache, loc. cit., p. 154.

iron in excess over ferric as it should be with aegirite absent. The relative proportion of the alkalies is not notably different but their total is higher by 0.65%. Mineralogically these differences correspond to much less quartz and to a greater preponderence of albite over microcline than in the coarse-granite, the ratios being — Feldspar to Quartz, 2.84 (fine-granite) and 1.67 coarse-granite, and Albite to Microcline, 1.25 and 1.02 resp.

In columns 11 and 12 the peripheral rocks of the Neponset Valley granite intrusion, described by Professor Bascom and already alluded to are given. It can be seen at a glance from these analyses, and the same is fully borne out by the microscopic characters given by Professor Bascom, that the peripheral phases of the Neponset granite are, like the granites themselves, quite sharply contrasted chemically and mineralogically to those of the Quincy, Mass., granite.

Rosival measurements have also been made on thin-sections of the fine-granite from other localities to determine their approximate mineral composition. These are given below: —

Mineral Composition of Fine-granites computed from Rosival Measurements.

	Ruggles Creek, Quincy. (type analyzed, No. 10.) (a.)	Wyman's Hill, Weymouth. (b.)	Pine Tree Brook Reservation. (c.)	North of Great Dome (Reservation). (Altered.) (d.)
Quartz	22.9	24.3	24.50	25.8
Microperthite	66.4	67.4	66.	67.1
Riebeckite,	10.7	8.3		
Soda-iron rich pyroxene and Hornblende			9.5	7.1
	100.0	100.0	100.0	100.0

These show a fairly close agreement, but some variation, just as has been shown to exist in the coarse-granite, appears to exist in the fine-granite from different localities. In (a) and (b) the dark silicate is riebeckite; in (c) and (d) some pyroxene is present, and they are also more altered, while the habits of the hornblende and pyroxenes are not quite so favorable to accurate measurement.

The Blue Hill Porphyries.

Granite-porphyry: quartz-feldspar-porphyry.

Distribution; Megascopic Characteristics.— The porphyry with its variations into quartz-feldspar-porphyry is the contact phase of the granite magma over that part of the field enclosed within the limits of the Blue Hill Reservation, and occupies, therefore, all of the more elevated part of the field. It is found outside of the Reservation only in the relatively small but, nevertheless, important tract known as the Pine Hill area, which lies immediately east of, and is continuous with the Reservation. Here the porphyry is associated with fine-granite and with a more basic phase of the contact zone, the darker colored, rhombenporphyry. The same is true of the Pine Tree Brook area and in both, it is worthy of note, that patches of the original cover of Cambrian slates remain. The porphyry cover does not reach quite to the northern edge of the Reservation but is cut off along a line that stretches across the top of Rattlesnake Hill and thence runs a westerly and southwesterly direction as far as the alkaline rocks extend. The areal continuity of the porphyry is broken in three places by masses of aporhyolite, or felsite, as it has been called for convenience in the field. The general outlines of these masses are indicated on the map. Considered as later in age than the porphyries and granite by Crosby, this rock is by the writer believed to be of earlier consolidation and it is against the felsite that the magma consolidated with some of its most interesting textural variations.

It is quite impossible to define the extent or exact relative amounts of the different phases of the porphyry, partly on account of their transitions into one another, partly because of their very irregular distribution and partly because of the difficulties of distinguishing minor variations in heavily weathered and lichened outcrops. The relative importance of the different varieties and their relation to each other can, nevertheless, be made out with certainty. What is here termed granite-porphyry is in areal distribution and in volume the most important rock. It is, as would naturally be expected, the phase that immediately overlies the granite and while in some parts of the area (Pine Hill, for example) it passes gradually into the granite, in others it changes suddenly into the porphyritic phase of the granite. The thickness of the porphyry cover varies greatly from a few feet (on Pine Hill) to about 200 feet (estimated) on Rattlesnake Hill.

Though this last thickness may be exceeded in the western part of the Blue Hills, it is thought to represent very roughly the present thickness of the porphyry.

The least altered material obtainable from the old quarries on the east end of Rattlesnake Hill shows the granite-porphyry phase to be a holocrystalline rock having much the appearance of a rather fine grained granite (for which it is usually mistaken on first inspection) of a prevailing light, greenish-grey color. Closer inspection shows clearly that it consists of abundant phenocrysts of alkaline feldspar and quartz embedded in a finely granular groundmass in which appear numerous irregular specks or grains of black mineral. The feldspars are the more abundant phenocrysts. They are elongated parallel to the edge 001–010, have a somewhat tabular habit on 010 and although usually rounded or broken on the ends, show nevertheless, a tendency to form rather acute terminations. They may measure as much as 8 mm. long, 5 to 6 mm. in breadth by 2 to 3 mm. in thickness, but the average is smaller. A chatoyancy, characteristic of the cryptoperthitic feldspars, may sometimes be seen (this is well shown on polished surfaces). The quartz forms rather inconspicuous rounded grains usually smaller than the larger feldspars. The fracture of the rock is much like that of the fine-granite and the jointing is likewise finer than in the coarse granite, with a strong tendency to the formation of sharply prismatic blocks.

While reddish stains may be seen in a few of the feldspars of almost any specimen, there are streaks and irregular patches in which red spots are very abundant and characteristic. The grey variety of the granite-porphyry is interlaminated, as it were, with streaks of considerable regularity and persistence of a darker phase. This is dark grey to almost black, and recalls the association of the dark and light grey coarse-granite with which it is doubtless strictly analogous.

Alteration of the porphyry produces a whitening, generally accompanied by a slight brownish or reddish discoloration of the feldspar phenocrysts, while the groundmass becomes grey or grayish blue owing to the breaking up and dissemination of the dark constituents. More advanced alteration produces a general breaking up of the groundmass.

Over large areas in the hills, the granite-porphyry appears in a form that may more properly be termed in the field a quartz-feldspar-porphyry than a granite-porphyry, for although, as shown by the microscope, the grain of the groundmass is but little finer than that

of the variety above described, the distribution of the dark mineral through the groundmass from one cause or another, renders the latter quite dense in appearance and of a peculiar grey or bluish-grey color. The phenocrysts are more conspicuous and all the more so when the feldspar is whitened or slightly stained (pink or brown). This type of rock is abundantly exposed for observation on the broad, gently rounded, smooth ledges characteristic of the northerly slopes of the hills and is a very characteristic feature of the area.

This last rock is scarcely to be distinguished from the phase with a truly dense groundmass into which it grades, and which also has a wide but irregular areal distribution. If anything the phenocrysts are slightly less abundant than in the former, the quartz forms rounder and more prominent grains and the groundmass is more varied in color and often darker. The color may be dark-grey, bluish-grey, pale-green or even dark-red to brown and less commonly of a purplish-red. The last mentioned colors belonging to exposures which have suffered a more complete oxidation of the iron-bearing minerals. Many ledges exhibit a heterogeneous structure. The grey or bluish-grey porphyry contains angular fragments, usually of the yellowish-green color, varying in size from ones measuring a few millimeters across to ones upwards of several inches in their largest dimension; also numerous streaks and blotches of the similar material, of varying width and length. These streaks and fragments by their arrangement often show a pronounced flow structure; again the fragments are so numerous as to constitute a breccia. Alteration further accentuates the heterogeneity. At one point on Heminway Hill the two varieties are so mingled together as to produce the appearance of a tuff. The brecciated character of the porphyry is clearly connected with the immediate contact of the magma with older rocks and is sufficient evidence that the contacts were at most only a short distance from the present surfaces of the rocks as now exposed, and that erosion has removed very little of the intrusive rock, a point that seems to be entirely borne out by the notable scarcity of rocks of the alkaline type in the conglomerates and other sediments of later age. The streaked porphyry referred to by Professor Crosby [32] as occurring on the south side of the Blue Hills both in situ and in the basal beds of the Norfolk-Basin conglomerate is undoubtedly of this type and its heterogenous structure is not, as was supposed by him, due entirely to differential weathering.

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[32] op. cit. p. 359.

In several localities in the Hills, notably on the north and northeast slopes of the Great Blue Hill and on the southern extension of Heminway Hill, there are large outcropings of a porphyry in which the feldspar phenocrysts are megascopically quite inconspicuous. The quartz phenocrysts are fairly numerous but small. The groundmass is aphanitic and usually of a dark brownish red or purplish color. In some places it appears to grade into the more crystalline porphyry about it; in others the transition is sudden, almost sharp, although always perfectly sealed. The sharpness of the transition here as with the other types — granite, fine-granite and granite-porphyry — is a characteristic relation.

In the region about Wampatuck Hill, the porphyry at the contact with the aporhyolite is of the very dense quartz-porphyry variety. The quartz phenocrysts are small and numerous, the feldspar is megascopically subordinate while the groundmass (where not strongly weathered) possesses a peculiar yellowish-green color which the microscope shows is due to the presence of many minute aegirite microliths. Going away from the contact the rock changes within a short distance — varying perhaps from 6 to 18 inches — into the variety with more abundant phenocrysts and this in turn changes rapidly but gradually into the granite-porphyry of the Rattlesnake Hill type. In the finer grained rock of the contact are many fragments, clearly of the contact phase of the porphyry itself and others seemingly of the aporhyolite.

Along the easternmost portions of the contact with the felsite in the Pine Hill Area, the porphyry at the contact presents a somewhat different charcter. At the immediate contact it is of the dense quartz-porphyry type and this shows breccia and flow-structures. Within a few inches this is succeeded quite suddenly by a coarsely porphyritic type which is confined to this mode of occurrence. Here the feldspars are larger and, when not broken or rounded, show acute terminations approaching the "rhomben" type. They are often visibly broken and resealed. In size they frequently measure a centimeter in length by 5 to 7 mm. in breadth by 3 to 4 mm. in thickness. The average is somewhat under these figures. The quartz grains are fewer in number and also larger than in the run of the porphyry, sometimes rivalling the feldspars in size. The groundmass is dense and usually of a grey or bluish-grey color though in streaks and patches it is greyish or yellowish-green. In this coarse porphyry near the contact are streaks and fragments of the finer material. These are in part portions of the coarse porphyry reduced to a fine-grained rock by

movements along the contact, in part portions of the finer grained contact quartz-porphyry. The zone of coarse porphyry near the extreme eastern end of the felsite mass is from three to four feet wide. Further west the band broadens out somewhat. Going toward the granite the groundmass becomes gradually coarser in grain, the dark mineral appears in distinct spots resembling more the hornblende of the granite and the rock passes gradually into the granite which, however, retains, for an indeterminate distance, a porphyritic texture and this, as has been already noted, is always an indication of a near approach to the granite-porphyry.

Small cognate Xenoliths of a dark colored rhomben porphyry similar in all respects to those described later under the heading of "Xenoliths" (p. 275) are found, sometimes quite abundantly in the coarsely porphyritic zone, almost up to the actual contact. These are also found, but more sparingly, in the granite-porphyry and granite immediately succeeding.

At the eastern end of the felsite, the breadth of the entire porphyry zone is, so far as it can be determined, only about 15 ft. Going west it broadens rapidly (30 ft.). This width holds nearly to the top of Pine Hill and then still further broadens (50–100 ft.) while at the same time the coarse-porphyry type disappears, and porphyry of the Rattlesnake Hill type replaces it.

In many parts of the Blue Hills the phenocrysts of the porphyry are quite inconspicuous, the rock having a relatively dense and non-porphyritic appearance. The microscope shows, however, that this texture has been produced by a breaking of the phenocrysts through movements in the mass before crystallization had stopped and by the very general recrystallization of the constituents, particularly the feldspar.

Those varieties of the porphyry in which the phenocrysts are less numerous and in which the groundmass is relatively dense might be classed as Paisanites [33] but the greater part of the porphyry appears to the writer to be too abundantly phenocrystalline and its groundmass too coarsely crystalline to be properly classed under this name, although in mineral and chemical composition they are closely related to the original paisanite.

In closing the description of the field characters of the porphyry one more important feature must be noted. Throughout large portions of the higher elevations of the hills, numerous, angular inclusions

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33 Osann, Tschermaks Min. u. Pet. Mitt. XV Band.

of a dense to very finely crystalline rock rather sparsely sprinkled with minute black specks of hornblende are found. These are usually small rarely measuring more than a few inches across. When altered they are of a light-grey or light, bluish-grey color and usually show a few small phenocrysts of feldspar. They belong to the alkaline series, and seem to be essentially identical with the porphyry in composition, but appear to differ in texture from the inclusions in the brecciated portions of the porphyry before alluded to. These correspond closely in many respects to paisanite.

Microscopic characters of the Porphyry: — The granite-porphyry from Rattlesnake Hill in the eastern part of the Reservation will first be described, for it is here that it is perhaps best exposed and where fresh material for sections and chemical analysis can be most easily obtained.

In thin-section the light greenish-grey porphyry, which is considered the normal type, is seen to consist of abundant phenocrysts of feldspar (ca. 40%), quartz (ca. 12%) (see accompanying table, column I), areas of hornblende and pyroxene (mostly aegirite), in part as distinct grains but largely in the form of poikolitic intergrowths with the groundmass, all embedded in a fine groundmass of microperthite, quartz, hornblende, and aegirite. Accessory aenigmatite, magnetite, hematite, zircon, fluorite and occasional calcite and astrophyllite are also present.

Table of Rosival estimates of Quartz and Feldspar Phenocrysts in Porphyry.

	I	II	III	IV
Feldspar	40.5	32.2	19.0	39.1
Quartz	12.4	16.3	14.5	6.4
Groundmass	47.1	51.5	66.5	54.5
	100.0	100.0	100.0	100.0

I Unaltered Granite Porphyry, Rattlesnake Hill, average measurements of two sections.
II Quartz-feldspar-porphyry, ledge S. of Administration Road, S. of Wampatuck Hill,— 1½ feet from aporhyolite contact. Made on one large section.
III Same, 3″ from same contact.
IV Coarsely porphyritic phase of contact porphyry. Contact east end of aporhyolite Pine Hill, West Quincy. Average of two extra large thin-sections.

Among the phenocrysts, the feldspar greatly predominates. Before modification by breaking and later recrystallization, the feldspar

crystals seem to have attained a fair degree of perfection in their crystal form. Cut parallel to the macropinacoid the crystals are often nearly square. There is usually an elongation parallel to the edge 001–010. Again the elongation is parallel to both this direction and the prismatic axis yielding tabular forms. The prism faces are often strongly developed as is also the y, ($\bar{2}01$) face, the latter tending to give acutely terminated crystals. As noted in the megascopic description, the feldspars occasionally reach a length of 8 mm. or more but the largest dimension usually seen in section will not exceed 3.5 mm. and the average is not much over 1 mm. Twinning is common after the Carlsbad law, less common after the Manebach and still less so after the Baveno law. Leaving aside later enlargements, one may observe many straight edges, but the outlines are very generally curved and the terminations are commonly rounded or irregular. A great many of the phenocrysts have been broken by movements in the crystallizing mass, giving rise to irregular fragments of varying sizes and shapes, and rendering it difficult to tell just how far gradation in size as a result of normal growth extended. It appears, however, certain that there was a continuous gradation in size down nearly to that of the groundmass individuals. Upon the margins of the phenocrysts is a narrow, but sharply marked zone of orientated feldspar substance of later growth (see Figures II and III, Plate 1). Outwardly this zone fades into the groundmass and while often of uniform width entirely around the phenocrysts, it more often varies considerably especially where the contours of the older crystal are irregular, broken or indented. This zone contains many minute, rounded quartz grains, tiny microliths of aegirite and sometimes riebeckite, and is clearly of groundmass age. As it is often seen developed on the broken surfaces of the phenocrysts, its deposition clearly took place subsequent to the fracturing of the latter. This enlargement on many of the smaller, more irregular feldspars is proportionally much broader than on the larger phenocrysts, its area often exceeding that of the enclosed grain. These smaller feldspars grade downward in size practically to groundmass dimensions and form in effect a part of the latter. The original feldspar material includes a few early pyroxene crystals (or such replaced and mantled with aegirite), but is free from other inclusions. Where recrystallized or invaded by albite, the phenocrysts contain abundant shreds and fibers of riebeckite and aegirite grains.

With low powers, the phenocrysts appear fresh and homogeneous, with higher powers considerable portions of the crystals and, rarely,

almost an entire crystal, appears also homogeneous. A great part of the feldspar, however, generally shows a very fine lamination, (cryptoperthitic) which is parallel to the usual direction of the perthite intergrowth. As the margin of the original crystal outline is approached, the lamination becomes more distinct and two sets of lamellae can be made out whose optical properties are those of albite and microcline. The perthitic structure of the marginal zone of later feldspar is slightly coarser (see Figure II, Plate 1).

In irregular streaks and patches through the body of the crystals the microperthitic structure is more distinct, and this coarsening is invariably accompanied by the occurrence of fine dust-like particles characteristic of the potash member of the granite microperthite. Sections of the homogeneous and cryptoperthitic parts of the phenocrysts parallel to M, (010) have an extinction measured on the 001 cleavage of from 12 to 13 degrees. Such sections show the immergence of an obtuse bisectrix. Basal sections give a nearly or quite parallel extinction. An acute positive bisectrix is obtained from sections near 100 with an axial angle similar in size to that of orthoclase. These properties are those of the cryptoperthite (anorthoclase) as described by Brogger, and of the feldspar phenocrysts described by Osann [34] in the Paisanite from West Texas.

The smaller, and usually more irregularly shaped crystals lying in the groundmass are for the most part microperthite (see Figure II, Plate 1), this, and the fact that the enlargements of the phenocrysts are also microperthite, as well as the feldspar of the groundmass proper, is important in connection with the relations of the cryptoperthitic and microperthitic structure, as will be pointed out later.

A striking feature of the phenocrysts is the extent to which they are replaced by albite. Many crystals, particularly the longer ones, are crossed transversely by narrow streaks of a more strongly polarizing, colorless material (see Figure III, Plate 1). In it are often minute crystals of aegirite. This substance is evidently albite. It is continuous with, and of the same orientation as the albite member of the microperthite in the later marginal zone. These streaks represent transverse fracture lines in the phenocryst along which albite set free from the unmixing (see later Part II) of the original feldspar substance or from the crystallizing groundmass, or both, have entered. Many instances are also seen where the albite has developed as a line of minute crystals extending across the phenocryst, following the line

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[34] Tschermaks Mtt. XV, p. 436.

of cracking, and again the fine material of the groundmass as a whole has frequently been forced in along cracks. Occurring sometimes irregularly in the body of the phenocryst or orientated parallel to the trace of the albite twinning, are often small, irregular to tabular grains of albite. In a great many other cases the replacement of the phenocryst by albite takes the form of curiously irregular masses,[35] which project into the original feldspar substance often replacing as much as a quarter or even two-thirds of the crystal. This albite is sometimes finely twinned, though usually the twinning is confined to a few stripes and is often lacking altogether.

The quartz phenocrysts are less abundant, forming about 12% of the rock. The largest grain measured was 3.5 mm. in diameter but the average is much smaller being in the neighborhood of 1 mm. The size most commonly seen is, however, somewhat larger than this. While occasionally showing a fairly well marked crystal outline, the quartz is usually much rounded and is often embayed by the groundmass. Its grains are sometimes granulated or, like the feldspar, broken apart and almost without exception show abundant evidence of crushing movements in the broken and strongly undulatory extinctions. The quartz contains the same inclusions of bubbles and minute black grains as the quartz of the granite, but is practically free from other inclusions except where fractured and then blue hornblende needles or small aegirites occur in the quartz. A very narrow rim of later growth may frequently be noted about the quartz, but it is much narrower and less conspicuous than the corresponding rim about the feldspar and seems often to be wanting.

The hornblende is relatively abundant and occurs in elongate masses of irregular or rudely elliptical outline which are in great part poikilitic intergrowths with the feldspar and quartz of the groundmass. In size, most of these areas are comparable with that of the smaller phenocrysts of quartz and feldspar and rarely exceed 2 mm. in their longest dimension. In the interior of many of these groups is massive or nearly massive hornblende, frequently enclosing pyroxene (see Figure I, Plate 1). The massive material passes gradually into the poikilitic intergrowth and, while about the edges there are slightly connected or unconnected grains, more distant from these masses there is little hornblende present other than a few shreds of secondary origin.

The poikilitic hornblendes show a strong tendency to form along

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[35] Compare albitization of feldspar in coarse-granite noted earlier.

the margins of the enlarged feldspar phenocrysts which served as points of attachment and sometimes entirely surround them. The smaller microperthitic feldspars of phenocrystalline age with their enlargements are even enclosed by a single group along with groundmass microperthite and quartz (as shown in Figure II, Plate 1). The hornblende, with the possible exception of the massive centers, obviously belongs to the groundmass period of crystallization.

In relatively thick sections or with crushed material, the hornblende possesses a prevailingly dark-blue or greenish-blue color. In good thin-sections, however, the characteristic color is a deep green or a bluish-green and the purer blue tones appear about the periphery or in streaks, and only rarely makes up any considerable portion of the more massive parts. The other characteristic ray (across the cleavage in 010 sections) is colored light yellow, light yellowish-green or light brownish-yellow. The extinction, in part, is that of riebeckite, but as in the granite, the extinction of the greener hornblende is much larger (ca 35°), indicating an alkali-hornblende, probably a cataphorite. The optical elongation is very difficult to determine owing to the deep colors and low double refraction but is negative for the blue type and probably positive for the catophorite.

The texture of the hornblende is well described as "spongiform," or more accurately; as domoikic with relatively fine to coarse xenocrysts. The feldspar and quartz xenocrysts show about the same range of sizes. They are irregular to tabular in habit while the quartz xenocrysts are commonly round.

Aegirite is the most abundant pyroxene but some other variety is present, of augitic appearance. The augitic pyroxene occurs in certain of the feldspar phenocrysts and also in the form of larger crystals in the groundmass, often surrounded by the hornblende (see Figure 1, Plate 1). It has sometimes a pale brown color but is usually a pale greenish-yellow. Rarely the augite material extends to a sharply marked line about which is a rim of deep-green aegirite. More often the augite appears as such, only at the center, and is succeeded outwardly by an indefinitely bounded green, aegiritic looking material. The depth of color increases toward the margin. The extreme edge appears to be aegirite. Again no augite can be seen, but the green to deep-green material with, however, the habit of the augite, forms a core which is indefinitely bordered by aegirite. Twinning on *a*, 100 occurs as do also zonal structures, but the latter lack sharpness. The aegiritic material is often finely granular, and may include fluorite grains, and much indeterminate dust. Occasionally

the pyroxene core is replaced by many subradiate to diverse, aegirite prismoids. The optical properties of the augite are apparently normal, but with the development of the green material these properties become rather indefinite, the double-refraction is too low and the extinction too large for aegirite. The most characteristic thing about this pyroxene material is the rich yellowish-green to deep-green shade belonging to the alkali-pyroxenes. Scattered through the groundmass are fairly good sized crystals of rich green pyroxene which show no trace of augite and would be taken for aegirite or aegirite-augite, and yet, their double-refraction is also low except about their margins, and the optical properties are poorly defined. The characters just outlined may indicate that augite in small quantity was crystallized at an early period (enclosure in the feldspars) and that subsequently as the concentration of the aegirite molecule increased, the augite was not only encrusted by the aegirite but became in large measure replaced by it. It should be noted that the feldspars in which the augite occurs resemble strongly the feldspars to be described as occurring in the more basic phases, which are marginal differentiates of the magma, and the suspicion is strong that the augite (and its enclosing feldspar) represent crystals which have formed, early in the period of crystallization. The analyses indicate that, as in the rhombenporphyry, the augitic looking pyroxene is rich in the CaF″-molecule. That true aegirine-augite is present the writer can find no very positive proof. The bulk of the aegirite is found as minute and usually irregular grains scattered through the groundmass.

Grains of a red to dark-red mineral, believed to be aenigmatite, occur embedded in the green pyroxene and in the hornblende. The same mineral has also a very characteristic and fairly abundant distribution through the groundmass. Its mode of occurrence may perhaps be described as "clustered." That is to say, it is made up of from perhaps ten to one hundred or more minute grains, for the most part unconnected, lying close together amidst the quartz, feldspar and aegirite grains of the groundmass (see Figure I, Plate 1). The grains are irregular in form with perhaps a slight tendency to an elongation parallel to a poorly developed cleavage. The larger ones will hardly exceed a few hundredths of a millimeter, the rest ranging down to tiny round particles 0.005 mm. in diameter. In a single cluster the majority of the grains have nearly or quite the same orientation. Their color, and such other of their optical properties as can be made out, seem to be the same as those given earlier for the aenigmatite of the granite. The larger grains are commonly slightly attached to

small adjacent grains and it may be that the clusters represent loosely connected poikilitic growths, the individual members of which, have been for the most part separated, but only slightly or not at all de-orientated by slight movements in the groundmass. Upon alteration they become opaque, apparently due to the formation of magnetite or ilmenite, or else they alter to limonite (?) blurs. In some instances they are seen accompanied by a development of astrophyllite fibers as is also the case with the aenigmatite of the granite.

The groundmass, aside from the later growths upon the feldspar phenocrysts and the poikilitic portions of the hornblendes and the aenigmatite, all of which are clearly of contemporaneous age with the groundmass and therefore properly belong to it, consists of a microcrystalline, inequigranular mixture of quartz, microperthite and aegirite with some accessory hornblende, mostly of secondary origin, magnetite, hematite, dusty particles, and calcite. The average grain of the quartz and feldspar will probably lie a little under 0.02 mm., the range from about 0.06 to 0.005 mm. The microperthite grains though apt to be sub-rectangular, particularly when enclosed in the hornblende, are usually quite irregular in shape, the quartz often shows a tendency to round outlines while the aegirite is scattered abundantly among the other minerals in the form of very irregular, small grains whose longest dimension rarely reaches 0.02 mm. and is usually measured in thousandths of a mm.

Texture.— Following the descriptive terms as proposed by Cross, Iddings, Pirsson and Washington,[36] the rock is sempatic and skedogranophyric, and in addition the groundmass is in part poikilitic.

Variations from the normal type on Rattlesnake Hill.— A portion of the greenish-grey porphyry is characterized by the presence of a reddish discoloration in the feldspar and a slightly darker color. In such the microscope shows the presence of abundant deposits of hematite along the cracks in the feldspar, of more abundant blue hornblende shreds in the groundmass, while the groups of poikilitic hornblende are bluer in color and often show secondary blue fibers and shreds developed about and upon them.

The strongly marked streaks of dark-grey porphyry are in the nature of indefinite interlaminations in the grey variety and blend rapidly into it. They differ from the lighter type in the presence of very abundant, fine, black dust in the groundmass and in the feldspar phenocrysts, particularly about the margins and along cracks; in the

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36 Texture of Igneous Rocks, Journ. Geol., **14**, No. 8 (Nov.-Dec., 1906).

presence of abundant, minute prisms, scales, fibers and irregularly shaped pieces of the blue-hornblende scattered through the groundmass, as well as fibers distributed along the cleavages and the direction of perthitic intergrowth in the feldspar; and in the nearly or complete disappearance of the aenigmatite. It is not probable that the dark porphyry originally differed from the grey in chemical composition and the present differences are undoubtedly due to alteration acting along zones or streaks in the porphyry mass as a whole. The alteration is different from that produced by purely superficial alteration, and is believed to be a result of deep-seated alteration (connected probably with late magmatic conditions) in the same way that the corresponding streaks of dark-grey granite are.

Characters of the Granite-Porphyry elsewhere in the Area.— Both the light and dark varieties have a very extensive development throughout the Blue Hills, but microscopic study of a large number of specimens from many points shows that there have been considerable changes effected in the various minerals beyond those which are thought to have developed during the late magmatic stage or in one immediately following it. These changes may perhaps have been effected during periods of profound geologic disturbance through which the region has passed, but the writer is inclined to think that they are in the main but a continuation of the modifications described as occurring in the Rattlesnake Hill porphyry, developed during the period subsequent to the consolidation of the porphyry, before the granite magma below had completed its crystallization and was still capable of giving off mineralized vapors, and perhaps also before all movements as a result of upward pressure of the mass beneath had ceased. Upon these are often superimposed the effects of superficial decay although these are limited to a thin surface layer. It thus happens that many exposures afford specimens which depart more or less widely in the details of the structure and composition from the normal type, and not a few in which only the remnants of the original structures remain.

Perhaps the most striking modifications thus effected are those shown by the feldspar phenocrysts. The changes in the original feldspar substance, believed to have been largely brought about during the latter part of the crystallization period or immediately following it, have been described for the normal porphyry, and are to be seen more or less strongly developed everywhere in the porphyry, although they are, to a greater or less extent modified by subsequent and more general alterations. So varied are the details of these

changes as a whole that it would be impossible to fully describe them and only brief description of some of the more characteristic and common types will be attempted. The accompanying microphotographs (Figures Nos. IV, V, VI, VII, Plates 1 and 2) will serve, perhaps better than the descriptions, to furnish an idea of the appearance of some of the types of modified phenocrysts. One of their most characteristic features is that great numbers of them are crossed by bands or streaks which are optically continuous with the marginal parts of the phenocryst and with it form a sort of mesh enclosing a heterogeneous mixture of feldspar material. Theses "streaks" nearly always show a distinct central division line representing an original crack now sealed, and extend partly or entirely across the crystal in slightly curved and often ramifying lines. Along the central division line there is usually a narrow streak of albite material, and on either side of this for a variable distance the material shows a faint microperthitic structure as do the marginal parts of the crystal with which it is in fact continuous. Further away from these bands, mingled with remnants of the original feldspar, may be more coarsely developed microperthite, or separately crystallized albite and microcline. Frequently these separate crystals are orientated parallel to the original feldspar or stand normal to the edges of the "streak"; again they are situated quite at random. They may take the form of rather short laths or are entirely irregular in outline. As a rule albite appears to be more abundant than would be expected if the changes were concerned wholly with the rearrangement of the albite and microcline of the original feldspar and there may have been a later introduction of albite. The microperthite can be easily recognized as a rule by the presence of minute specks, cavities, etc. in the potash member just as in the granite microperthite. Wherever this has been broken or replaced, the specks, etc. are absent, but needles of blue amphibole occur, sometimes with aegirite. Both aegirite and amphibole are commonly developed along the original division line in the "streak" and abundantly on either side of the streak as a whole. It appears that the cracks served as channels along which solutions acted, introducing probably some material from without and effecting changes for a short distance on either side in the original feldspar — a more distinct development of the albite and potash members — thus rendering such portions of the feldspar, like the outer margin, relatively more stable and permitting them to persist more or less intact while the less stable interior of the phenocrysts underwent a considerable and often a nearly or complete recrystallization and replacement. The question of the

instability of phenocrysts as originally formed will be discussed more fully in a later paragraph when the general question of the crystallization of the rocks will be considered.

In extreme cases, particularly where the rock shows otherwise evidences of extreme modifications, the phenocrysts have been reduced to a fine mixture of two feldspars in size of grain very near to that of the groundmass itself, and, if it were not for the preservation of a part of the "streaks" and marginal portions of the phenocrysts, one would be sometimes in doubt whether the rock contained feldspar phenocrysts or not. The introduction of the granular material of the groundmass along breaks in the phenocrysts is also a very common phenomenon.

Another conspicuous change is seen in the modification of the hornblende groups. The beginning of the alteration shows first in the loss of the highly spongiform appearance of the groups brought about by the development of minute rods or fibers of deep blue amphibole about the edges or replacing the original mineral. Further changes result in a general breaking up of the groups, the inner and more massive portions, where these occur, being also involved. Small clusters of prismatic to almost fibrous, deep blue amphibole of the riebeckite type, associated with abundant magnetite crystals, and often with recrystallized or secondary feldspar and quartz, take the place of the original group. At the same time more or less elongated prisms and more irregular grains develop in the immediate neighborhood, and to a greater or less extent, also make their appearance throughout the rock generally. The aegirite associated with the hornblende seems to be less easily affected but is nevertheless finally involved in the alteration. Still further changes, in which both long continued deep-seated alteration and more superficial decay doubtless play a part, more or less completely destroy the original hornblende and pyroxene and the resulting products, blue riebeckite shreds, magnetite with hematite and limonite or other ferruginous products, become generally distributed through the rock and only clusters of magnetite grains etc. remain to mark the position of the original dark silicates. Of course the microliths of the groundmass also suffer a corresponding alteration.

The quartz phenocrysts are often impregnated with the secondary amphibole, and in the more advanced stages, are broken up and the parts scattered. The quartz of the groundmass in these altered phases is perhaps rather more distinct than in the normal rock. This is in part because it is little affected by the changes, but also in part

because at times its grains appear to have suffered some enlargement. It thus happens, as a result of the changes enumerated, that the granite-porphyry is not infrequently reduced to a fine grained aggregate which shows only a faint indication of its originally richly porphyritic character. In such, where superficial weathering has developed a large amount of hematite, etc., the rock has the appearance of a feebly porphyritic, reddish or purplish felsite and may not at first sight be easily distinguished from the aporhyolite of this area.

Microscopic Characters of the Porphyry nearer the Contact.— As noted under the megascopic description, the porphyry undergoes a marked change in texture whenever its contact with the aporhyolite is approached, and although with the exception of the two special areas, Pine Hill and the Pine Tree Brook Reservation, no actual contacts with any other rock occur, there are considerable areas over which the porphyry shows, both in the hand-specimen and under the microscope, unmistakable evidences of being a contact phase.

Thin sections cut from several series of specimens, taken every few inches from the contact going toward the aporhyolite, show that the first change that becomes apparent is in the hornblende groups. They are smaller, relatively more numerous and tend toward an imperfect, short prismatic habit. While still intergrown with the groundmass grains they commonly show a tendency to grow about one or more of the groundmass grains as a center. The massive crystals are less numerous. The aegirite of the groundmass assumes a distinctly more prismoid habit, the crystals being short, stout and better formed, and they often show a tendency to form clusters and to a parallel arrangement. The larger aegirites have much the same habit as elsewhere in the porphyry.

As the contact is approached more closely there is a rather sudden change in the groundmass. It becomes much finer, the aegirite forms very abundant minute prismoids which are commonly arranged with a distinct flow structure about the phenocrysts. The riebeckite also forms minute rods and flakes with a somewhat elongated habit. Minute magnetite octahedra and hematite grains are abundant. The phenocrysts of feldspar and quartz are somewhat less numerous and the quartz has increased relatively to the feldspar (as shown by the Rosival measurements in the table, p. 243, Column II). Though frequently imperfect, particularly on one or two sides, and often broken, the feldspar crystals appear to have been well developed crystallographically as do also the quartz phenocrysts, the latter often showing a quite perfect di-hexahedral habit. The feldspars are

now almost wholly recrystallized to an albite-microcline microperthite which occasionally takes on a very curious habit (see below), and although there appears to have been some of the same albitization etc. as has been described for the granite-porphyry, the changes in the contact phases appear to have been more in the nature of a simple recrystallization. The later rims of groundmass age are either lacking or are developed to a slight extent. Many of the quartz crystals, locally, show a well developed rim of later growth. Occasional crystals or groups of hornblende seem to have been present as judged by alteration products. There is often a strong clustering of the aegirite microliths as if in an attempt to form a larger crystal, and there are quite numerous small prismatic crystals of aegirite. Many aggregates of aegirite crystals occur whose outlines and close packing suggest that they were originally formed from a homogenous crystal of pyroxene.

The curious mode of alteration of the feldspar phenocrysts which was referred to immediately above occurs rarely, and is not strongly developed in the contact porphyry as a whole. The finest examples were observed in slides from specimens taken a few feet east of the aporhyolite contact of Hemingway Hill. It is so unusual, so far as the writer's experience goes, that its peculiarities will be noted and illustrated by microphotographs. For the most part, the phenocrysts have been completely recrystallized into curious irregular areas of slightly radiate intergrowths of albite and microcline, giving the impression of a delicate tracery (see Figure VIIa and b, Plate 2). Occasionally the borders of the phenocrysts have been replaced, wholly or in part, by a band of short albite laths alternating with microcline (see Figure VIIa).

At the immediate contact and for a few inches away, the groundmass becomes extremely fine so that it appears almost isotropic with low powers, and is only imperfectly resolved even with very high magnifications. It consists of exceedingly minute prismoids of aegirite mingled with a feebly polarizing aggregate of quartz and feldspar; also with much fine dust, magnetite octrahedra and hematitic material. These latter may be due to alteration which has affected to a greater or less extent all of the specimens which it was possible to collect. Replacements of what appear to have been small pyroxene phenocrysts may be occasionally seen. The feldspar and quartz phenocrysts are less numerous and smaller, and the proportion of quartz relative to feldspar has increased (see Rosival measurements, table p. 243, Column III). The feldspar in all the slides examined is

changed into microperthite or a fine mixture of the two feldspars. Both the quartz and feldspar, particularly the former, originally possessed rather sharp outlines and the quartz shows less resorption than in many parts of the porphyry. Flow structures in the groundmass are very pronounced but there are no indications that the rock was ever, even in part, glassy.

As already noted, a characteristic of the porphyry near the contact is the presence of what look like inclusions, or of streaks and spots of different color and texture from the matrix. These are in large part unquestionably parts of the porphyry itself and the microscope indicates that they are in large part fragments of the immediate contact rock. Some of the streaks show evidences of much recrystallization, and seem to be drawn-out and recrystallized fragments. At the contact with the aporhyolite are found many small rounded or subangular fragments which megascopically seem to be certainly pieces of the aporhyolite; microscopically however, they do not show precisely the same structures, nor are they like the other inclusions of the porphyry itself. They are believed to be parts of the aporhyolite subsequently recrystallized and otherwise changed during its inclusion in the hot porphyry mass. . At a number of points, where at present no contact with other rocks is to be found but which from their structure show conclusively that a contact was originally only a short distance away (vertically), the brecciated character of the porphyry is most striking. In such, for example, a short distance from the porphyry-aporhyolite contacts on the small knolls south of Wampatuck Hill and again in the extensive ledges northwest of the aporhyolite contacts on Hemingway Hill, the finest example of the brecciated porphyry are to be observed. In these cases the matrix is a quartz-feldspar porphyry with marked flow structure and of the type found two or three feet distance from the actual contacts. The texture of these inclusions is usually quite irregular, and it is doubtful if any of them represent original textures. Many of them appear to have been drawn out and moulded, as it were, by the enclosing matrix. In such there has been much recrystallization of the original constituents. Growths of aegirite and the two feldspars are common, normal to the surfaces of the phenocrysts, and to the margins of the inclusion itself. The aegirite and microperthite form curious radiating intergrowths and in some, a poikilitic intergrowth of aegirite and albite resembling the "diabase" structure, may be seen. Many of the inclusions contain what appear to be vein structures and some are, in common with the enclosing porphyry, crossed by minute quartz veins. Fluorite is pres-

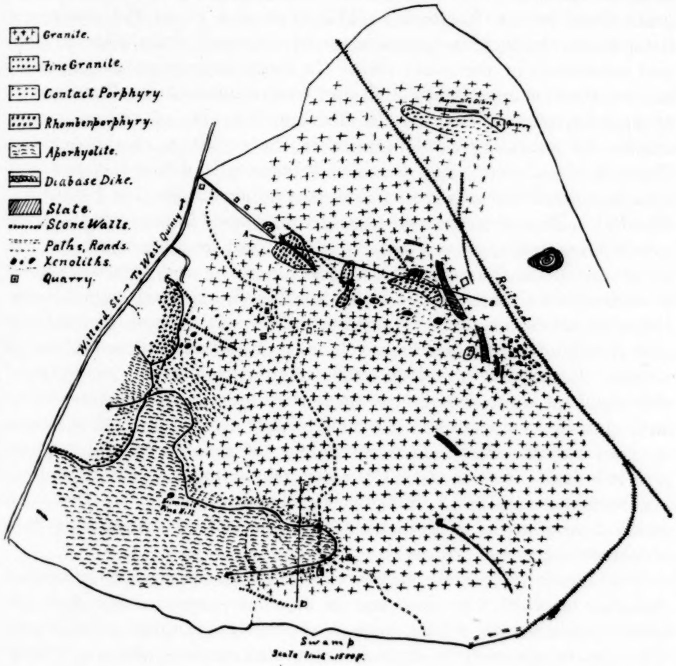
ent and is often so abundant as to be megascopically visible. These structures seem to the writer to be explained by the hypothesis that they were produced by the breaking and tearing off of the first consolidated portions of the porphyry magma, which had formed against the cooler rocks of the contact zone, by movements in the still partially fluid, and doubtless highly viscous, mass beneath. With these were doubtless fragments of the aporhyolite not now clearly distinguishable. Once included, the fragments were modified in shape and more or less recrystallized by the hot, enclosing mass, with its mineralizing vapors. The porphyry of the contact zone may, therefore, as a whole, be regarded as possessing a somewhat modified taxitic structure.

Contact Porphyry of the Pine Hill Area.— The contact phase of the porphyry as developed on the eastern slopes of Pine Hill are deserving of special notice (see here special map of Pine Hill area). In the first place the distance from the granite to the felsite aporhyolite as has been noted earlier, is much narrower than elsewhere, ranging from perhaps 15 ft. at the extreme eastern end to perhaps 30 ft. a little east of the summit of the hill. The narrower contact zone indicates that here, as held by Professor Crosby, a deep part of the contact zone is exposed and the characters of the rocks fully bear this out. At the immediate contact with the aporhyolite we find a very dense, not conspicuously porphyritic rock. In fact, it is often impossible without microscopic preparations to tell when one is dealing with the aporhyolite and when with the porphyry. The similarity is increased by the fact that the porphyry at the contact, here as elsewhere, is much brecciated, giving rise not only to the appearance of flow structure but also to that of small apophyses of dense material running into the porphyry, and these might easily be mistaken for apophyses of the aporhyolite cutting the porphyry. Such they were supposed to be by Crosby and they naturally constituted the strongest argument for the intrusive nature of the aporhyolite.[37]

A few inches back from the contact, the rock quite suddenly assumes a strongly and coarsely porphyritic habit. The quartz and feldspar phenocrysts here attain the largest size met anywhere in the field and the feldspar is relatively more abundant than elsewhere. (See table, p. 243, Column IV, of Rosival measurements on the

[37] To illustrate how natural was this mistake regarding the nature of this contact the writer may say that he collected several suites of specimens illustrating as he supposed the succession of types across the contact, only to find, when they were sectioned, that they were all of the porphyry and that the aporhyolite had not been reached. The true contact was found two or three inches beyond.

porphyry). The feldspars show much the same characteristics as those in the Rattlesnake type, except that there is a stronger development of the y, $\bar{2}01$ face, with a corresponding approach to the "rhomben" type of habit, and that the later additions of groundmass



Special Map of the Pine Hill Area, West Quincy, Mass.

This map is based on an outcrop map made for the writer under his direction by Mr. J. D. Mackenzie, to whom the writer is indebted for a painstaking piece of work. The patches of the rhombenporphyry and slate have been purposely exaggerated in size, as have also the xenoliths, in order to have them show on a map of this scale. Many more small xenoliths are scattered through the granite elsewhere in the field but have been omitted from the map. The southern portion of the area has a general elevation of about fifty feet above that of the northern half. While the surface is extremely rough, the actual differences in elevation are inconsiderable.

age are small or fail. The hornblende and aegirite also show much the same characters as in the Rattlesnake type although they have been disturbed more by movements in the rock. Fluorite is particularly abundant in the larger aegirites in the form of small included grains. The groundmass is less regular in texture and grain than in the Rattlesnake Hill type and is on the average a little finer. In fact the groundmass varies much from slide to slide and sometimes in the same slide. In some there is an inequigranular mixture of quartz and feldspar with abundant small prismoids of aegirite, with flakes, shreds, fibers and grains of riebeckite; in others the riebeckite predominates to the exclusion of the aegirite. There is often a very fine poikilitic intergrowth of the feldspar and quartz generally attached to the feldspar phenocrysts (see Figure VI, Plate 1). Flow structures are strongly developed in many parts of the groundmass and are less conspicuous or almost wanting in others. In all of the specimens examined, magnetite grains and octahedra were abundant, and many of the larger hornblendes showed signs of considerable alteration so that it is certain that part, at least, of the fibers and shreds of riebeckite seen in the groundmass are secondary in origin. It may be noted that the irregularities in the structure of this phase of the porphyry are quite distinctly visible to the eye on well glaciated exposures in the field. They appear as rather faintly marked streaks and patches of slightly differing color and texture, and it is easily discerned that the general direction of the flowage in the rock was parallel to the contact. The aporhyolite on the other hand shows, so far as the writer has observed, no megascopic flow structure near the contact.

The band of coarsely porphyritic rock is apparently somewhat variable in width but does not in any case exceed a few feet. It passes rapidly into a rock with a distinctly granular groundmass. The quartz phenocrysts show well rounded outlines and the "rhomben"-like habit of the feldspars persists. Their size is on the average about the same as in the preceding phase and is very close to that of the larger feldspar grains of the granite itself. The hornblende becomes distinctly more granitic in habit, though it still includes the groundmass grains; the groundmass generally begins to assume a finely granular texture.

As one recedes still further from the contact the demarkation between phenocrysts and groundmass becomes less and less distinguishable and the minerals assume gradually the relations to each other found in the porphyritic type of the granite and this, as noted earlier,

passes eventually into the normal Quincy granite. The width of the zone measured normally, from the contact to the point, or rather interval, in which the rock can be fairly termed a granite, in some places is certainly not over 10–15 feet while in others, less easily determined, it is probably in the neighborhood of 30–40 ft. How far it is to where the normal Quincy granite is typically developed can not be estimated exactly, but it is safe to say that it is measured by not over a few tens of feet in this part of the area.

After passing the summit of Pine Hill the character of the contact porphyry changes (fault?) and it is less favorably exposed for study. It appears to pass into the Rattlesnake Hill type but as the extreme western end of the area is reached there is again a change, fine granite and more basic phase of the porphyry coming in, which are indicative of a near approach to a slate contact, such as in fact is actually exposed in the northern part of the area as shown on the special map.

On the southern and sharply rounded face a small hill to the east of the railroad track running east of the Pine Hill area, is a thin cover of granite-porphyry. This lies on the granite and forms a sharp contact, marked by the development of abundant long hornblende crystals, which dips a rather low angle to the south. Immediately beneath this porphyry numerous riebeckite pegmatitic dikes and stringers occur in the granite.[38] This porphyry is unusual in its texture. Over small irregular areas it is strongly and coarsely porphyritic (feldspar with subordinate quartz) otherwise it is rather feebly and unevenly porphyritic. The microscope shows, that the feldspar, phenocrysts and groundmass, is a microperthite like that of the granite but contains a greater proportion of albite, and the latter is very strongly developed marginally and as distinct crystals. The quartz tends toward micrographic intergrowths and its total amount is relatively high. Aegirite is abundant alone and intergrown with the riebeckite, which here has often an unusually great elongation; accessories as in the granite. It has possibly been affected by pneumatolitic action connected with the pegmatitic intrusion, but in any case it shows a variation from the other types of granite-porphyry that is of interest. Its feebly porphyritic phase resembles closely the more acid type of xenoliths.

So far the characteristics of the porphyry with relation to its contact with the aporhyolite have been considered. What its contact phases were with relation to the higher slate and intermediate

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[38] Warren & Palache, op. cit., p.

contacts were we can only conjecture. But there appears to be no good reason for supposing them to have been in any essential particulars different from those obtaining for the aporhyolite at the same levels. As for the porphyry contacts with the slates at *deeper levels*, such as in the northern part of the *Pine Hill area* and in the *Pine Tree Brook Reservation*, we find them characterized by the presence of a peculiar and characteristic basic phase which will next be described.

Chemical characters.— A specimen of the light grey porphyry was obtained from well inside a large quarried block from the eastern side of Rattlesnake Hill. Thin sections showed the specimen to be almost perfectly fresh, except for a little calcite. The results are the averages of closely agreeing duplicates.

	13.		10.	14.
	Per cent.	Molec. Ratios.		
SiO_2	72.88	1.214	71.41	73.35
ZrO_2	.10	.004	.10	
Al_2O_3	12.30	.122	12.74	14.38
Fe_2O_3	1.67	.011	1.75	1.96
FeO	2.10	.029	2.33	.34
MnO	.10	.001	.10	
MgO	.09	.002	.06	.09
CaO	.87	.014	.85	.26
Na_2O	4.43	.071	4.59	4.33
K_2O	4.90	.052	5.00	5.66
H_2O-	.15		.10	
H_2O+	.31	(.017)	.56	
CO_2	.30	.007	.40	
TiO_2	.35	.004	.38	
P_2O_5	tr		.22	
Total	100.55		100.59	100.37

Spec. G. of No. 13 at 20° C., 2.667.

13. Granite Porphyry, Quarry, from east side of Rattlesnake Hill, Blue Hills Reservation. Analyst, C. H. Warren.
10. Fine Granite, Ruggles Creek, Quincy.
14. Paisanite, Mosques Canyon, Apache Mountains, Transpecos, Texas; A. Usann. T. M. P. M., XV, p. 439, 1895.

The norm is as follows:

Quartz	26.64	$\frac{Sal}{Fem} = 12.1 > \frac{7}{1}$; Class 1.
Orthoclase	28.91	92.23 Salic Minerals.
Albite	36.68	$\frac{Q}{F} = .40 < \frac{5}{3} > \frac{1}{7}$; order 4, quarofelic.
Acmite	.46	$\frac{K_2O + Na_2O}{CaO} > \frac{7}{1}$; Rang 1, peralkalic.
Diopside	3.45	
Hypersthene	.76	7.60 Femic Minerals.
Magnetite	2.32	$\frac{K_2O}{Na_2O} = .7 < \frac{5}{3} > \frac{3}{5}$; Subrang 3; sodipotassic.
Ilmenite	.61	*Liparose.*

The rock would, therefore, be termed a sodic-hornblende, aegirite-granophyro-liparose. The phase with a dense groundmass found at or near the contacts would be a graniphyro-liparose.

The mineral composition for the porphyry has been calculated approximately as follows (calculated to 100%).

Granite Porphyry			Fine-Granite
Quartz	26.7	26.7	23.3
Albite	34.8	63.8	66.4
Microcline	29.0		
Pyroxene, Hornblende	8.1	9.5	
Magnetite	.76		
Ilmenite	.61		
Zircon	.10		10.3
	100.0		100.0

Ratio: Feldspar to Quartz

	Porphyry		Fine-Granite
	2.35		2.84
Albite to Microcline	1.20		1.25
	54.5	Albite	55.6
	45.5	Microcline	44.4
	100.0	Microperthite	100.0

In chemical composition the rock resembles closely the fine-granite. It appears to be less feldspathic and more quartzose and slightly lower in dark silicates. The mineral composition of the two in these particulars is shown above in parallel columns. The microperthite is closely similar in the two. The soda-iron silicates are, in the case of porphyry, aegirite with some aegirine-augite, cataphorite and riebeckite and a little aenigmatite, while in the fine-granite only riebeckite is present. This illustrates well how slight chemical difference together with different conditions during consolidation (as evidenced

by the marked differences in texture of the two rocks) may determine quite surprising differences in the minor essential minerals.

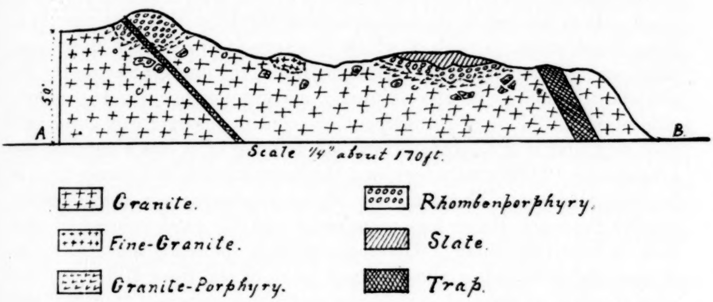
In order to see if there are chemical differences between the granite-porphyry and its contact phases two partial analyses were made: one (No. 11), on as fresh a specimen as could be obtained from the porphyry-aporhyolite contact just south of Rattlesnake Hill. This specimen came from the immediate contact and under the microscope showed small phenocrysts of quartz and feldspar embedded in a very fine groundmass rich in aegirite microlites. The second specimen (No. 12) came from about a foot from the porphyry-aporhyolite contact near its eastern end on Pine Hill, West Quincy. The specimen is of the coarsely and profusely porphyritic type with feldspar phenocrysts of large size, and is the type characteristic of a deeper level of the contact, with these analyses is given in part that of the normal granite-porphyry of Rattlesnake Hill (No. 10).

	10 Granite-Porphyry Rattlesnake Hill		11 Contact Porphyry S. of Rattlesnake Hill		12 Contact Porphyry from E. of Pine Hill	
SiO_2	72.88		73.15		72.88	
Al_2O_3	12.30		13.07		12.03	
Fe_2O_3	1.67	3.77	2.18	3.89	2.67	4.19
FeO	2.10		1.71		1.52	
CaO	.87		.68		.40	

While the specimens were somewhat altered the analyses indicate that there has been little, if any, real differentiation in the porphyry. The almost exact reversal in the relations of ferrous to ferric iron of the extreme contact phases, in comparison with the rock of the main mass of porphyry, with but a slight gain in the total iron oxides, is striking and in keeping with the strong development of aegirite in the contact rock, and may point to stronger oxidizing conditions near the contact, though in view of the variation in these oxides in the granite itself, its significance is doubtful.

Dark, Alkali-Feldspar- or Rhombenporphyry.

This rock is the one to which Professor Crosby applied the name "basic-porphyry." While the rock is distinctly darker in color and suggests a basic rock in its general appearance, and in fact, is truly more basic than the other rocks of the area, it is not a particularly basic rock containing in any case not much under 60% of silica. The term "rhombenporphyry," which will be used here in describing this rock, seemed an appropriate one on account of the "rhomben" habit of the feldspar phenocrysts, and also, on account of the strong



SECTION THROUGH THE NORTHERN PART OF THE PINE HILL AREA.

This section is intended to illustrate the relations of the intrusive rocks against the intruded slate where the latter formed relatively deep projections into the igneous mass (deep contact levels). The rhombenporphyry and slate masses have been somewhat exaggerated as to size in order to show them to better advantage. The section is however based on the outcrops as shown on the special map of this area.

resemblance of the rock, particularly in its microscopic characters, to certain rather fine-grained and somewhat altered rhombenporphyries which the writer had examined from the Laurvik region in Norway. The typical rhombenporphyry, it is true, is characterized by much larger phenocrysts and differs chemically from the present rock in some respects.

This porphyry, as held by Crosby,[39] is a marginal differentiate of

[39] op. cit., pp. 370–371.

the magma developed along relatively deep slate contacts of the batholith. If we may include the dark colored, porphyritic knots which are, as will be shown, very closely related chemically and mineralogically and which are believed to be of identical origin with the rhombenporphyry we may say that, a relatively basic feldspar-porphyry phase was developed not only against the deeper projections of slate but also to a small extent against the deeper contacts of the aporhyolite, and in locations such as those just underneath the granite-porphyry in the higher levels of the contact zone, where the magma remained fluid for a sufficient length of time under the cover of its own porphyritic phases to permit differentiation to take place.

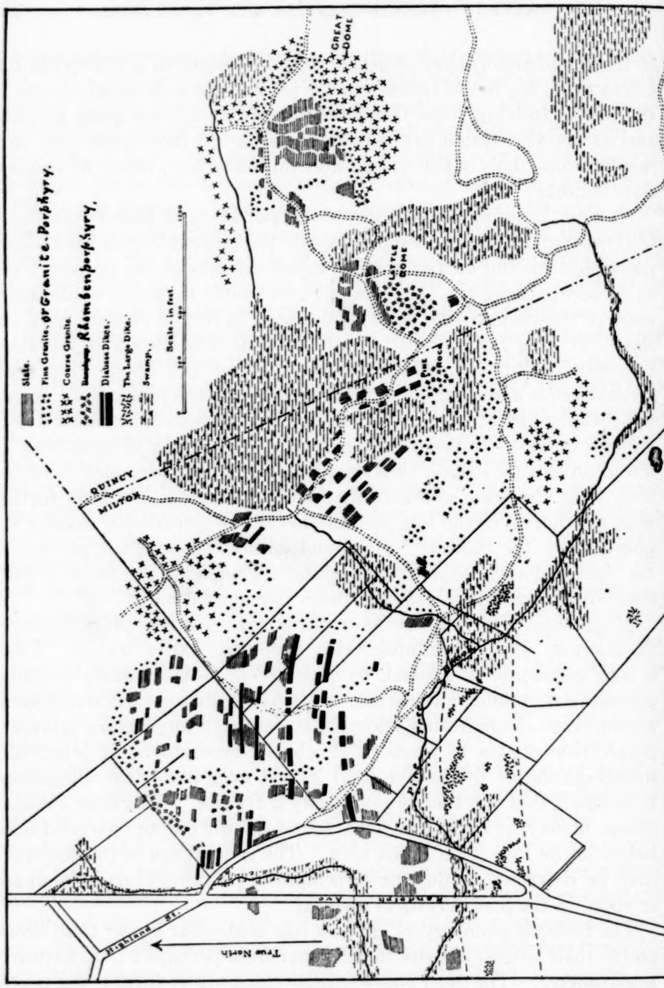
Distribution.— The areal distribution of this rock is relatively very small. It is limited in its occurrence to the Pine Hill and the Pine Tree Brook areas, in both of which it occurs at or near the slate contacts, and is associated with developments of the fine-granite and with abundant xenöliths in the adjoining granite-porphyry and porphyritic granite. None of its outcrops are continuous over any considerable area and it is doubtful if any single mass of it has a continuous area of over 10,000 square feet, or a thickness measured by more than a few tens of feet. The majority of its exposures are considerably smaller than the figure just mentioned and the total volume of the rock is relatively small. The best exposure for study and collection of material is found in the northern part of the Pine Hill area (see special map), at the end of a short street which runs east from Willard Street in West Quincy. At this point is a prominent ledge which in the past has been worked for road metal. The rock has been quarried in an open cut which gives excellent exposures for a distance of some 50 feet in length and to a depth of about 15 ft. Going east from this ledge toward the railroad track several other smaller masses of it occur. These are situated very close to two small outcrops of Cambrian slate and are perhaps in contact with it. They are, as shown by abundant contacts, enclosed in a granite-porphyry. At a point a few hundred yards southwest of the first mentioned outcrop a number of smaller masses occur enclosed in the porphyritic granite of the contact type. The largest of these masses will not measure more than a few feet in their greatest dimension and from this they grade down to fragments which are comparable in size to the larger xenoliths found in the granite generally throughout this area, as will be noted later. Small dark patches are abundant in the granite of this type from this location along an east-west line as far as the railroad where, in a large and finely glaciated ledge, the inclusions

of the rhombenporphyry, together with inclusions of a somewhat different type, are found in the granite on a scale seen no where else in the field. Judging from the character of the granite along this line and its known relation to the contact porphyry, these inclusions cannot lie more than a few yards, and probably feet, below an original slate contact.

Another prominent exposure of the porphyry is found just north of the Great Dome, particularly beside the Sawcut Notch road which passes by this hill on the north. Small dikelets of the porphyry are to be seen cutting the slate and a considerable exposure of the main mass of the rock at this point is also seen in chilled contact with the slate. A little farther west within the Pine Tree Brook Reservation (see special map) proper, on the Little Dome and about Pine Rock are numerous and excellent exposures although the rock is very deeply weathered in all of them. Several small inclusions of the slate are to be seen in the rhomben-porphyry and a thin veneer of slate may be found on several ledges, thus confirming the intimate relation of the rock with the slate contacts as shown elsewhere. A little further west and north, in the lots just outside of the reservation at near the point where the Sawcut Notch road enters it, abundant patches of the dark colored porphyry are found included in the large granite dike which here cuts across the slates (see special map).

Megascopic Characters.— As regards the relative proportions of phenocrysts and groundmass, this porphyry varies widely. From a rock consisting of a black to dark greenish-black, finely granular groundmass, holding a few white or greyish white to nearly transparent phenocrysts of unstriated feldspar, it varies through more profusely porphyritic phases to those in which the groundmass is practically indistinguishable to the eye, and indeed even under the microscope is so small that the rock is practically a syenite. This later extreme phase, it may be noted, has been found in only one or two good sized ledges in the Pine Tree Brook area. The general run of the porphyry may be described as dopatic to sempatic, viz. groundmass dominant or equal to the phenocrysts in amount.

The feldspar phenocrysts are as a rule somewhat longer than broad and in their longest dimension will range from perhaps 2 mm. to nearly a centimeter. The most characteristic thing about them is the gently curved sides and the acute terminations of a large proportion of them. The habit is quite strongly "rhomben." A considerable number of them are not simple crystals but consist of two or more parts. It may often be noticed that these parts terminate in two or more



Special Outcrop Map of the Pine Tree Brook Area after Crosby.

This map is taken from Professor Crosby's Blue Hill Report and serves to show the general relations of the slate, rhombenporphyry fine-granite, granite-porphyry and coarse-granite. Some coarse-granite cuts the fine-granite etc. which cannot be shown on this scale map. There is also coarser,

porphyritic granite in the central portion of the westernmost dike, which has been described in some detail in the text as being remarkable for the abundant xenoliths of rhombenporphyry enclosed in the coarser grained part. The original scale of this map has been reduced in reproducing it for this paper so that 1 inch equals approximately 1000 ft.

distinct points on one, or even both ends of the group. Minute dark grains of pyroxene and specks of secondary minerals may be seen in the feldspars, particularly about the margins. (See Figs. VIII and IX, Plate 2).

With a pocket lense the groundmass has a slightly oily lustre in fresh specimens and is of a yellowish-black or to greenish-black color. The grain is rendered somewhat indistinct by the alteration products which are always present. Occasional grains of augite may be seen together with tiny yellowish crystals of epidote, black magnetites or ilmenites and sometimes patches of compact greenish black secondary material. Rarely a grain of pyrite occurs. Superficial weathering causes the groundmass to rust (brown) and retreat leaving the whitened and roughened feldspar in relief.

Microscopic Characters.— The original minerals present in the type analyzed are, soda-orthoclase,[40] crytoperthite or microperthite and augite with accessory quartz, apatite and magnetite or ilmenite. With these are secondary green hornblende, epidote, biotite, titanite, magnetite, calcite, sericite, pyrite and limonite.

The habit of the feldspar phenocrysts at the close of the porphyritic stage of growth seems to have been that of very acutely terminated crystals with rounded contours, the crystal being frequently, in fact, of almost lensiform outlines in cross-section. The tendency to form composite groups is marked, the individual members being united by quite irregular surfaces and often arranged in a slightly divergent manner, and with separate terminations all pointing as a rule in the same direction. The original outlines, doubtless those which give so often the impression in the hand specimen of sharp boundaries, are more or less obscured in thin section by the later growths of groundmass age. The central parts of the feldspar crystals are in part of homogeneous structure, in part very finely striated and in part dis-

40 The term anorthoclase will not be used here for these feldspars as they appear to be monoclinic and the term anorthoclase (used by Brögger for closely similar feldspars in the rhombenporphyries of the Laurvikite area Norway) implies triclinic symmetry. These feldspars may of course be triclinic with a very small extinction angle, in fact an apparent angle of extinction of 1° to 2° was observed on two or three basal cleavage fragments.

tinctly microperthitic. Albite or pericline twinning were not noticed. Measurements made on cleavage fragments give extinctions nearly or quite 0° on 001 sections and up to 13° or 14° on 010. The outer part of the original phenocrysts is usually distinctly more perthitic and gives the impression of having a stronger double-refraction, the effect doubtless of the distinctly crystallized albite. The close of the porphyritic stage of growth is not so sharply marked as a rule as in the granite-porphyry, but is nevertheless perfectly clear and extends around the individuals of a single group, showing clearly that the clustering took place during the porphyritic stage of growth. The later border zone of the phenocrysts is microperthite, similarly orientated to the interior and including small augite grains of the groundmass, often abundantly, and these are commonly orientated parallel to the perthite structure. There is little augite that can be truly said to be included in the central and earlier parts of the phenocrysts. The feldspars have suffered more or less from alteration, and besides sericite and calcite contain, often abundantly, minute crystals of hornblende, epidote and magnetite. In the syenitic phase of this rock exposed in the Pine Tree Brook area, the feldspar, while retaining traces of the characteristics above noted, is much more granitic in habit and consists of a finely developed microperthite.

The augite appears to have developed only to a small extent during the phenocrystalline stage. A few crystals with, at most, only a feeble attempt at definite crystalline form are found lying for the most part entirely in the groundmass although some of them lie in the marginal parts of the phenocrysts and penetrate perhaps for a short distance into the older portions. These augites include, and are indented by, the feldspar of the groundmass. They rarely measure 3 mm. in length and are usually not over 1 mm. long by perhaps $\frac{1}{2}$ or $\frac{2}{3}$ as broad. Their margins are irregular and have attached to them, particularly on the ends, smaller grains like those of the groundmass generally. They include apatite grains and magnetite or ilmenite. In common with the augite of the groundmass they are of a pale purplish color and appear to be ordinary augite although the chemical analysis of the rock indicates that they are rich in the "CaFe-" molecule. They are occasionally polysynthetically twinned. Their alteration is exactly the same as that of the rest of the augite.

In the more highly porphyritic types it is only rarely that a phenocryst of quartz can be found. When such occurs, the crystal is rounded in outline and is always bordered by a strong development of augite grains.

The groundmass consists essentially of microperthite (rarely a little separate albite) augite and ilmenite or magnitite. The feldspar is in excess and now contains more or less abundant secondary hornblende, epidote, etc. The feldspar grains are xenomorphic and roughly equidimensional and of somewhat variable size. The most commonly observed dimensions are from 00.1 to 00.2 mm., the range from perhaps 0.05 to 0.3 mm. The augite lies between the feldspar, indents it, and is often included in the larger grains as well as in the groundmass additions to the feldspar phenocrysts. They have the habit either of rounded grains, short irregular prisms, or of considerably elongated (parallel to $\dot{c}'$) prismoid forms with irregularly developed edges. A strong tendency is shown for the smaller prisms to grow end to end forming a small train, and many of the prismoid crystals are little more than loosely joined shorter crystals grown end to end. This habit is doubtless due in part to the growth of the augite along the direction of the perthite intergrowth in the feldspar, and it thus also happens that the augite crystals have a parallel orientation over small areas. Ilmenite or magnetite grains are commonly present in or about the augite. The augite throughout shows a strong tendency to alter into a green or bluish-green hornblende often accompanied by a lighter green, micaceous mineral apparently a more or less altered biotite. The alteration appears to be a complicated process which involves not only the augite but the magnetite or ilmenite grains usually found with it, and the adjoining feldspar. The resulting products gradually replaced the augite and spread out into the feldspar particularly along cracks and crystal boundaries. The hornblende is mostly of the finely prismatic, aggregated type, though some appears in the form of more massive crystals; the other principle product consists of fibers or plates or is closely felted with a radiate structure. It is strongly pleochroic in light yellow to pale green tones, shows a parallel extinction and a strong double refraction. It appears to be some form of biotite with a chloritic alteration. It often forms patches occupying the position of original augite and ilmenite. In or about these areas are more or less hornblende, epidote prisms and sometimes well formed crystals of titanite. Occasionally these patches may be observed 3 or 4 mm. across, and these doubtless represent not only the replacement of augite, etc., but point to an accumulation of the secondary products about centers of alteration and replacement. In the more syenitic types of this rock (Pine Tree Brook area) the hornblende has been recrystallized into good sized crystals and aggregates of hornblende which replace the already small amount of groundmass and enhance the highly granitoid appearance of this phase of the rock.

As noted, the magnetite, or more probably ilmenite, is almost always closely associated with the augite. Apatite is quite abundant and is found in or about the augite and also in the feldspar. The quartz is mostly confined to the groundmass where it forms extremely irregular masses moulded in between the other minerals. Its amount is usually very small but in some of the less highly porphyritic types it is more abundant and, as will be noted later, it begins to be more plentiful both in the form of phenocrysts and in the groundmass, in xenoliths of the porphyry further removed from the contacts, and particularly in the xenoliths, such as are abundantly developed in the granite of the Pine Hill area.

In some portions of the less porphyritic and more siliceous types a green to greenish-blue, alkali hornblende makes its appearance, poikilitically enclosing the groundmass feldspar. In these, also, the pyroxene in part shows by its green color the presence of the aegirite molecule, and there is an obvious passage toward the more acid phases now represented largely by the cognate xenoliths to be considered later.

A study of the porphyry-slate contact exposed on the Sawcut Notch road shows that the porphyry forms a chilled contact against the slate. The feldspar phenocrysts become somewhat smaller in size and less numerous as the contact is approached, while at the same time the groundmass becomes very fine. The actual contact seen in thin section shows the two rocks in sharp contact. The slate shows a slightly coarsened grain in some of its minerals and there is a patchy development of biotite plates immediately about the contact within the slate. On the whole, while the slate is hard and very dense, the contact metamorphism appears to have been relatively slight.

Chemical Characters.— The great variation in the texture of this rock rendered the selection of a material for analysis difficult. Several specimens, taken from the old road-metal quarry in the northern part of the Pine Hill tract, furnished the best material, although the alteration of the rock even here, is greater than desirable for chemical study. The sample used was assembled from good sized fragments broken from specimens which represented the principle variations in texture noted, varying from profusely and coarsely porphyritic ones to those finer in grain and only moderately porphyritic. The analysis, therefore, is believed to represent very fairly the average composition of this differentiate of the Quincy-Blue Hill magma. The average of duplicate analyses is given under column 13.

	13 Percent		
SiO_2	58.77	.969	58.82
Al_2O_3	15.78	.155	21.06
Fe_2O_3	2.33	.014	3.26
FeO	6.03	.083	.70
MnO	.10	.001	1.38
MgO	.24	.006	3.03
CaO	3.55	.063	6.83
Na_2O	4.47	.073	3.70
K_2O	5.29	.056	1.26
H_2O-	.29		
H_2O+	1.22		
$T:O_2$	.94	.011	
P_2O_5	1.45	.010	
	100.46		100.04

Sp. G. = 2.72

No. 13. Dark, alkali-feldspar- or rhombenporphyry, Pine Hill Area, West Quincy, Mass., Analyst, C. H. Warren.

In the parallel column is an analysis, by G. Forsberg, of a rhombenporphyry from Slotsberg n. Tonsberg, Norway (W. C. Brogger, Z. K., XVI, p. 35, 1890).

The norm of the "Quantitative" Classification is as follows:

Quartz	4.44	$\frac{Sal}{Fem} = 3 < \frac{7}{1} > \frac{5}{3}$. Class 11.
Orthoclase	31.14	81.06 Salic Minerals.
Albite	38.25	
Anorthite	7.23	$\frac{T}{Q} = .05 < \frac{1}{7}$; Order 5: perfelic.
Diopside	.99	
Hypersthene	7.86	$\frac{K_2O + Na_2O}{CaO} = 4.9$; Range 2; domalkalic.
Magnetite	3.25	17.13 Femic Minerals.
Ilmenite	1.67	$\frac{K_2O}{Na_2O} = .76$. Subrange 3; sodipotassic; Monzonose.
Apatite	3.36	
	96.19	

It is impossible to calculate, other than approximately, the mineral composition both on account of the altered character of the rock, and the uncertainties as to the exact composition of the various minerals, nor did it appear, in order to help out the situation, advisable to attempt to separate the feldspar and analyze it on account of the included pyroxene and secondary minerals. The approximate mineral composition (to 100%) of the rock has been calculated as follows: —

Quartz	1.00	1.0	Ratio, Albite to Microcline = 1.30
Albite $Ab_{95}An_5$	40.2	71.3	
Microcline	31.1		
Pyroxene, etc.	19.4	19.4	Albite 56.3
Magnetite	3.2	8.3	Mic. 43.7
Ilmenite	1.7		100.0
Apatite	3.4	100.0	

The low magnesia indicates that the pyroxene is largely a lime and ferrous iron—rich member of that family (augite-hedenbergite). It is interesting to note that the proportion of Or: Ab + An as deduced by Vogt [41] for the cryptoperthites, (anorthoclase) of the rhombenporphyries associated with the Laurvikite of South Norway is 42: 58, which is very near that found here viz. 43.7: 56.3. With the exception of the silica percentage, high total alkalies, and the relative proportions of the alkalies present in the feldspar, there appears to be little resemblance chemically between this rock and the rhombenporphyry whose analysis appears above. Nevertheless the rock, texturally and mineralogically, belongs to this type and its occurrence with the alkali-granites of this area is interesting and significant.

Cognate Xenoliths.

Patches differing in texture and usually of darker color, are characteristic of the coarse-granite and its porphyritic phase and of the porphyry along the deeper contacts. They are without exception derived from the magma by some process of differentiation and are believed to represent for the most part, if not entirely, fragments, perhaps somewhat modified, derived from marginal facies, immersed and frozen in the consolidating magma. Following Harker [42] we shall call these masses cognate xenoliths. As has been already noted, they are especially abundant in those parts of the field where the contact porphyry is thin, and where also the more basic, feldspar-porphyry is developed — that is, in portions of the field which represent relatively deeper parts of the contact zone, where the magma was less extensively chilled, and where differentiation could take place. They are likewise strongly developed in the porphyritic phase of the granite immediately underneath the heavy cover of granite porphyry (as on the

[41] T. H. L. Vogt, T. M. P. M., **24**, No. 6, p. 524 (1906).
[42] National Hist. of Igneous Rocks. A. Harker, p. 347 (1904).

north side of Rattlesnake Hill) where apparently again the magma had an opportunity to differentiate. They also appear in the granite dikes which cut the porphyry cover from the underlying granite, as shown near Slide Notch and in the Pine Tree Brook areas.

It is noteworthy that in the thick mass of granite-porphyry as exposed at Rattlesnake Hill, and generally in the same rock which is characteristic of the higher levels of the contact, that cognate xenoliths are of very rare occurrence. The same is true of the fine-granite. Inclusions of the fine grained, little or undifferentiated contact phases, as has been noted earlier, are abundant at the contacts and many angular masses, undoubtedly of the same origin, are to be found in many of the porphyry ledges throughout the Blue Hills proper.

Although there is a strong localization of the xenoliths in the regions indicated, they are also common throughout the granite mass as a whole. The contrast in texture and mineral composition is, to be sure, not as marked in the latter class of occurrences, but it is the belief of the writer, founded on extensive observation about the quarries, that there is not a cubic yard of granite in which some more or less marked variation in texture cannot be found on careful examination. Single surfaces of one or more square yards may be obtained which are practically free from noticeable variations in grain, and many such are to be seen in the finished blocks at the quarries, but a careful inspection of the sides and back of the blocks will show one or more patches differing from the normal more or less sharply. Quarrying has penetrated into the granite to a depth of over 300 ft. and the xenoliths are still in evidence, although the writer feels pretty certain that in depth they are either somewhat less numerous than higher up, or at least they are less sharply distinguished in texture.

The Pine Hill area in West Quincy offers the best opportunity to study the xenoliths which are associated with the deeper contact zones. The darker colored, fine grained and usually porphyritic type is common in the granite-porphyry almost up to the aporhyolite contacts and is also found in the porphyritic-granite immediately underlying it. In this phase of the granite generally, and particularly, in the northern part of the area in the immediate neighborhood of the heavy developments of the rhombenporphyry, this type of xenolith is very abundant, but it is associated with types that are lighter in color and with a more granitoid groundmass as well as with some which are feebly or nonporphyritic. In the more normal granite which is exposed over the eastern and southeastern parts of this particular area but which is always prone to pass into the porphyritic

granite, and doubtless underlies it everywhere by only a few feet or yards, the xenoliths are relatively abundant, so much so in fact, that all attempts to use the stone commercially have been unsuccessful.

At a point a few hundred feet west of Willard Street, northwest of Pine Hill (see special map), several good sized masses of the rhombenporphyry occur included in the granite, and with them are smaller masses grading down to those only a few inches across. These megascopically and microscopically differ in no essential particular from the less highly porphyritic phase of the type rhombenporphyry, previously described, except that they show a small development of an alkali-hornblende poikilitically enclosing the groundmass feldspar, and in this respect show a gradation toward the granite-porphyry. Again on the eastern side of the area, beside the railroad track, is a beautifully glaciated ledge where is to be seen the finest exposure of xenoliths anywhere in the entire field. The granite is here of the porphyritic type and is literally packed with xenoliths, chiefly of the dark, fine grained porphyritic type, and it is here that they can be studied to the best advantage. In size they vary from tiny patches consisting sometimes of a single feldspar phenocryst, surrounded by a few millimeters of dark groundmass, to masses two to four feet in length by usually $\frac{1}{3}$ to $\frac{3}{4}$ as much in width. Their shape varies greatly: — subangular, round, lenticular, illiptical, greatly elongated with rounded ends and straight or gently curved sides, one side curved and the other irregular or deeply embayed by prongs of granite, or entirely irregular and invaded by tongues of granite. With the darker, are many lighter colored xenoliths, porphyritic, but with a more finely granitoid groundmass, in some cases conspicuously sprinkled with minute hornblende grains. These form separate masses and also sharply separated zones surrounding the darker xenoliths, or attached to them on one or two sides. An occasional mass of fine granite, of the same type as that found as larger masses only a short distance away, may also be found. The contacts of all of the xenoliths with the granite are sharp though perfectly sealed. There is no evidence of textural blending nor are there any reaction rims. The contacts of the lighter colored and more granular xenoliths, while likewise sharp, are naturally not so strongly marked to the eye as in the case of their darker companions. Examination with a lense shows that the contact is not, however, a simple line, but is indented by grains of the surrounding material and sometimes by small apophyses.

The darker xenoliths are here again strikingly similar in appearance to certain phases of the rhombenporphyry, and are composed of a very

fine dark green to almost black groundmass, in which is enclosed acutely terminated and often composite phenocrysts of feldspar. In some, the phenocrysts are relatively few, in others they are very numerous. In some of the xenoliths, quartz crystals are sparingly developed, and these are always characterized by a halo of dark mineral grains (usually hornblende) about them. Rarely small patches of hornblende or pyroxene may be seen. In very fresh specimens the feldspar phenocrysts are almost colorless and often show a fine chatoyancy. On weathering the feldspars whiten and the groundmass becomes dull black and less clearly crystalline.

Microscopic characters of the Xenoliths of the Contact Zones.— The close resemblance to the rhombenporphyry is quite as obvious microscopically as megascopically. The feldspar has precisely the same characteristics, even to the sharply marked rim of groundmass age, including prismoids and grains of pyroxene arranged parallel to the direction of perthitic intergrowth. The feldspar of the groundmass is also the same. The same phenocrysts of pale brown augite occur but these show a strong tendency to pass into a green variety, particularly about the margins. The pyroxene of the groundmass has about the same habit as that in the rhombenporphyry but is of a light to rather strong green color often, with a weak pleochrism. Its double-refraction is low, not exceeding that of ordinary augite, and its optical properties otherwise seem to be those of augite, but it probably contains some admixture of the aegirite molecule. Considerable hornblende is also frequently present in the groundmass. It occurs in part as a later growth on the augite, either in the form of minute prisms or needles, or in a more massive form, and in part with a poikilitic habit enclosing the groundmass feldspar. Strongly pleochroic; α, pale greenish-yellow or brown; β, very dark green; γ, deep olive-green; γ makes an angle of as high as 33 degrees on c', it appears to be an alkali hornblende near catoforite. Biotite occurs as a finely foliated alteration product of the augite and ilmenite or magnetite. The latter is abundant in, and associated with, the augite and also scattered through the rock. Magnetite forms grains and sharply bounded octahedra and may be in part secondary, since it has been noticed that in the rocks of this area the magnetite of secondary formation is apt to form sharply bounded crystals. Apatite is present. Most of the xenoliths show considerable alteration resulting in the presence of calcite, kaolin and ferruginous matter.

The darker type of xenoliths pass on the one hand through all gradations into a type lighter in color — greyish green — and with a

more distinctly crystalline groundmass and, on the other, there are gradations into fine grained types with few or no feldspar phenocrysts. So varied, in fact, are these xenoliths that detailed description is out of the question and only certain significant features can be noted. Where feldspar phenocrysts occur they are always characterized by a central core of more or less acute habit about which is a later rim usually, if not always, showing inclusions of the groundmass grains. In the more basic xenoliths the core is in part, if not entirely, homogeneous, or it is finely cryptoperthitic; in the more acid types the core is more distinctly perthitic, often wholly so. The quartz phenocrysts, which occur sparingly in the darker types, are always marked by a more or less strongly developed rim of pyroxene or hornblende; in the lighter colored and more siliceous types the quartz is more abundant and the margin of dark silicates is less marked or nearly wanting. In the more acid types, while some augite is present, it shows a tendency to pass into a green variety, and most of the pyroxene is distinctly green, slightly pleochroic, and seems to be an aegirine-bearing augite probably near augite, since the double-refraction is always much too low for true aegirine-augite. It is of earlier age than the hornblende, which in this type becomes rather abundant and grows about the pyroxene in part, and in part, occurs separately, enclosing poikolitically the feldspar of the groundmass. Most of the hornblende appears to be related to the catoforites although it is in part riebeckitic, particularly about the margins. The latter is also disseminated as shreds and fibers through the rock. Magnetite is an abundant alteration product, accompanied by some biotite. It may be noted here that some xenoliths occur in which little or no pyroxene is present, its place being taken by hornblende, apparently original, although it is true that all the xenoliths of this type that have come under the writer's observation are quite heavily altered, and it is possible that a part of the hornblende may be secondary after pyroxene. Apatite is common in the more basic types, less common in the others. Titanite is present in all, forming irregular masses sometimes associated with the hornblende, but it often lies between or wrapped about the groundmass feldspar and is believed to be wholly of secondary origin.

In the acid types fluorite is present in small grains with the dark minerals and also, like the titanite, wrapped about the feldspar. A little zircon is also present. In most of the xenoliths examined, alteration has produced considerable calcite, kaolin and other products.

The xenoliths of the fine-granite type show little evidence of gradation into the other types, in this respect resembling the fine-granite masses in the immediate vicinity from which they are thought to have been derived.

The xenoliths found in the Pine Tree Brook Reservation, and in the immediate vicinity, are essentially of the same character as those already described. When we come to consider the xenoliths found in the granite of Rattlesnake Hill just underneath the thick mass of granite-porphyry which there covers it, we find much the same characters but with certain differences. In the first place, the acute habit of the feldspar phenocrysts is not noted to the same extent as in the Pine Hill tract, and while there is a just as sharply marked cessation of the phenocrystalline period of growth, the inner core of feldspar is usually almost, if not quite, as distinctly microperthitic as the feldspar of the groundmass and often almost as coarse as that of the surrounding granite. The hornblende seems more highly poikilitic resembling more nearly some of the hornblende in certain phases of the overlying porphyry. Occasional grains of aenigmatite are also present with the dark minerals, and this mineral is also found in the porphyry above and in the granite. In the more siliceous xenoliths, round quartz grains make their appearance in the groundmass rims of the feldspar phenocrysts, and the quartz of the groundmass has also a distinctly rounded habit or is even poikilitically enclosed in the feldspar, a relation that is also observed in the granite-porphyry above. The many dark greenish-black or greenish-grey, fine-grained and non-porphyritic xenoliths which occur here contain abundant aegirine-augite and aegirite, together with hornblende, and although of much finer grain, are texturally much the same as the surrounding granite. Occasionally these show a feeble banding as if they had been drawn out during inclusion in the granite.

In general it may be said of the xenoliths which occur near the contacts, that they partake to a striking degree of the mineralogical and textural characteristics of the contact facies of the magma which are developed *en masse* in their immediate neighborhood. Though their margins are moulded, and more or less invaded by the enclosing rock, the actual contacts are sharp and there is no evidence of reaction between them, nor of any notable transfer of material from the enclosing magma to the xenolith. Their probable mode of origin as well as that of the xenoliths of the normal granite will be considered later, when the general process of crystallization, etc., of the magma is taken up.

Microscopic characters of the Xenoliths of the Normal Granite.— The

prevalence of xenoliths in the coarse granite of the quarries has been noted above. Mr. Dale[43] states that their sizes range from one half an inch to 2 feet by 1 foot, 6 inches; 2 feet, 6 inches by 2 feet, 6 inches; 3 feet by 4 inches, and 6 feet by 2 feet, but that they are usually small and roundish or elliptical in outline. The present writer is quite in accord with these statements. Mr. Dale also divides the "segregations" into three classes, which so far as their megascopic characters are concerned are substantially the divisions given below.

Although there appears to be more or less gradation and no sharp line can be drawn, three types may be made as follows: —

(1) Essentially fine-grained to almost dense xenoliths of a *dark* to *medium bluish* or *greenish-grey color;* usually irregularly, though not abundantly porphyritic, the phenocrysts being chiefly feldspar and quartz with occasionally irregular patches of pyroxene or hornblende. The phenocrysts are sometimes rudely clustered.

(2) Essentially fine to medium grained xenoliths of *light* to *medium grey color:*— about the same shade as the enclosing granite; usually contain a few, sometimes a good many phenocrysts of feldspar and quartz and occasionally irregular crystals of pyroxene or hornblende. The phenocrysts are not as a rule very evenly distributed and tend to form clusters.

(3) Fine-grained *greenish* or *yellowish-green* xenoliths often having a feeble banding; not usually porphyritic. These are substantially like many of type (1), and appear to differ from them chiefly in being more altered and in having been sometimes sheared, thus developing a banded structure.

The contacts of these xenoliths is essentially a sharp one, though naturally the grains of the surrounding granite project into the xenoliths about the margin and occasionally tongues of the granite penetrate them. There is never any sign of chemical interreaction between the two.

Thin sections of the darker colored xenoliths of type (1), show that they are essentially a pretty even-grained mixture of microcline-microperthite and some quartz, aegirite-augite, aegirite and green or blue alkali-hornblende. The latter and a part of the pyroxene often encloses the feldspar in poikilitic fashion. With these are the usual accessory minerals found in the granite. The lighter colored xenoliths of this type (1) are more siliceous and contain proportionally

[43] loc. cit., p. 96.

more aegirite. The phenocrysts of feldspar when present — which is usually the case — consist of a fine microperthite, and show, as in all of the xenoliths previously described, an inner core about which is a later margin enclosing few to many grains of the dark minerals or quartz. Here, however, the texture of the core is about the same as that of the rim. The feldspar and quartz of the groundmass are sometimes entirely xenomorphic, in other instances the feldspar is quite rectangular in outline, in others the quartz is characterized by a distinctly round habit and then is apt to be poikilitically enclosed in the feldspar. The pyroxene forms irregular elongated prismoids lying between the feldspar and quartz, also commonly enclosing the feldspar. The hornblende is wrapped about the feldspars, often forming poikilitic groups of some size. Slender shreds and fibers of blue, secondary hornblende may be abundantly distributed through the rock. Accessory minerals are as usual, although, as in the case of type (2), fluorite, zircon and titanite may be locally abundant closely associated with the quartz and often wrapped about the feldspar in very irregular masses. This suggests a later introduction of these constituents. In certain of these xenoliths the pyroxene shows a peculiar alteration and replacement. The centers of the majority of the pyroxene crystals are replaced, sometimes by a material which appears to be siderite, sometimes by a fibrous or foliated material of medium, mean refraction and high double-refraction, probably muscovite, but usually by both materials present in varying amount. Minute grains of magnetite and sometimes fluorite are associated with these. Decomposition of the siderite develops a yellow stain, and this can be seen in the hand specimen and is believed to account largely for the yellowish color of so many of the fine-grained xenoliths particularly of type (3). The replacement of the center of the pyroxene seems to have been accompanied by more or less recrystallization of the marginal parts which as a rule are granular and very irregular. Material from these has spread out into the surrounding microperthite, particularly along the lamellae of the potash member. The remaining pyroxene is in part aegirine-augite, though outwardly it appears to be aegirite. As augite is abundantly present in so many of the xenoliths of the contact types it is not improbable that the central parts of the pyroxene in these cases was augite, and that it has been decomposed and replaced by processes perhaps connected with pneumatolytic activities in the enclosing granite.

Microscopic study of the xenoliths of type (2) show that they are uniformly more quartzose and richer in aegirite than the others. In

the finer grained xenoliths the grain is quite uniform and will average under a millimeter; in the coarser, the grain may average from one to three millimeters or about the same as that of the fine-granite so abundantly developed in the eastern part of the area. The general texture of this type is granitic, with a feeble and usually irregular porphyritic tendency. The phenocrysts of feldspar, sometimes with quartz, may be clustered in patches of coarser granitic habit. Some trace of an inner core of distinct form may be seen in at least some of the feldspar phenocrysts, even in the coarsest grained types, but the phenomenon is more distinct in the finer grained ones. The feldspar in many of the xenoliths is precisely similar to that of the granite outside, except in size. In others there is a more distinct separation of the microcline and albite. Sometimes separate crystals of almost pure microcline and albite may be seen; but generally the two are intergrown, the microcline forming relatively good sized patches surrounded by finely twinned albite which determines the outlines of the crystal. The quartz is highly xenomorphic in some, in others it is rounded in outline and may be inclosed in the feldspar.

The pyroxene is aegirite. It is in part massive, of the same character as that of the granite, and is to some extent intergrown with riebeckite. The larger massive grains lie about the feldspar, sometimes enclosing them. Much of the aegirite is found lying between the feldspar crystals and penetrates quite deeply into their margins. In such instances it is of very irregular habit often being little more than a skeleton of loosely joined grains and minute prismoids tending to form a single elongated crystal. Sections cut through these irregular aegirites where they penetrate into the feldspar give the impression of a "spatter" of aegirite grains enclosed in the middle of a feldspar crystal. Aegirite in the form of small microlites together with shreds and fibers of blue hornblende are scattered through the feldspar generally. In some of the xenoliths, fluorite is not only present in the form of minute grains in the aegirite (as in the granite) but it also forms masses of considerable extent replacing the quartz. Occurring with it and of the same habit, is zircon. These minerals are both probably of pneumatolytic origin. Titanite is also present in formless grains and is perhaps of similar origin with the zircon.

Other inclusions in the Granite-Porphyry. The rarity of cognate xenoliths in the granite-porphyry of the Rattlesnake Hill type has been noted; also the occurrence in some parts of the porphyry, of very fine grained, angular fragments. These are perhaps best exposed for study in the vicinity of Scamaug Notch, and in many of the

smooth glaciated ledges which form Kitchimakin Hill. They vary in size from small fragments an inch or two across to those measuring upwards of a foot on a side. In color, when not oxidized, they are of a light to medium gray or bluish-gray. They are feebly porphyritic containing a few small phenocrysts of feldspar (rarely quartz) up to two millimeters in length. Microscopically they are found to consist of the same feldspar as the enclosing porphyry, quartz and riebeckite, magnetite and alteration products. The riebeckite is partly in the form of abundant small prismatic or flaky aggregates enclosing the groundmass minerals and in part in the form of tiny shreds and fibers. The quartz and feldspar are xenomorphic and somewhat variable in grain. The feldspar phenocrysts are often broken, as are the few quartz phenocrysts that have been noted in these inclusions. These inclusions resemble most nearly some of the fine-grained contact phases of the porphyry and doubtless are derived from such a source, having been broken off and included in the still fluid mass beneath the contacts, and then sunk, or were carried away, from their original place of formation.

Chemical characters.— Analyses of a number of the various types of xenoliths described would doubtless yield interesting results. The writer has, however, confined himself, to two types, partly on account of the labor involved and partly because it is believed that the microscopic evidence is sufficient to show the connection chemically and texturally between the various types. The two types chosen are extreme ones. One is a rhombenporphyry type resembling megascopically very closely the moderately porphyritic type of the rhombenporphyry, and came from a recently quarried block of granite from the northern part of the Pine Hill Tract not far south of the type locality for the rhombenporphyry. The microscope showed that the feldspar was the same as in the type rhombenporphyry; quartz is lacking almost entirely; augite is present but is much less abundant than a green, feebly pleochroic soda-iron type; soda hornblende of the green and blue types is present, and some black oxide minerals; some secondary biotite and other alteration materials are also present. The second chosen was a fine granite type of xenolith, the most quartzose and aegiritic found, and was taken from the granite of the Hardwick Quarry, Quincy. The results of duplicate analyses follow on p. 282.

In comparison with the chemical composition of the type rhombenporphyry the xenolith is slightly higher in silica, also in total iron oxides, and the ferric iron is proportionally higher as might be expected

	16		15	17	3
	Per cent	Ratios			
SiO_2	60.02	1.000	58.77	71.84	73.93
Al_2O_3	14.86	.145	15.78	13.55	12.09
Fe_2O_3	2.80	.018	2.33	2.50	2.91
FeO	6.57	.090	6.03	.39	1.55
MnO	.20	.002	.10	—	tr
MgO	.38	.009	.24	tr	.08
CaO	3.33	.059	3.55	.85	.31
Na_2O	5.64	.090	4.47	10.00 estimated	4.66
K_2O	4.26	.045	5.29		4.63
H_2O+	.78		1.22		.41
H_2O-	.20		.29		
TiO_2	.90	.001	.94		.18
P_2O_5	.63	.004	1.45		
	100.57		100.46		100.75

Sp. G. of No. 16 at 20° C. = 2.80.

16. Rhombenporphyry xenolith, from granite, northern part of Pine Hill, West Quincy, Mass. Analyst, C. H. Warren.
15. Rhombenporphyry,— Pine Hill, Mass. Analyst C. H. Warren.
17. Fine-granite type of xenolith, most quartoze type, Hardwick Quarry, Quincy, Mass. Analyst, C. H. Warren.
3. Granite from Hardwick Quarry. Analyst, H. S. Washington.

from the greater amount of pyroxene and hornblende and the presence of the $Na_2Fe_2''\ Si_4O_{12}$ molecule; Al_2O_3 is lower. Soda is here considerably in excess of the potash for the same reason. Lime is lower, though still relatively high for the Quincy rocks owing to the presence of the lime and ferrous-iron rich, augite. If we attempt to calculate the mineral composition for the groups,— feldspars, pyroxenes + hornblende, and accessories,— on the assumption that the proportions of potash feldspar to Ab + An is the same as in the rhombenporphyry (No. 15) it becomes at once apparent that much too great an amount

of alumina will then fall to the pyroxene and hornblende to agree with the general alumina-poor character of these minerals in the Quincy magma; also considerable free quartz would result, whereas little is really present. It, therefore, appears that albite is considerably more abundant, in the groundmass, than in the rhombenporphyry (and this agrees with microscopic observations so far as it is possible to judge in so fine-grained a rock). Working on the assumption, that with the exception of some soda combined with the ferric iron, this oxide goes into albite, we may venture a very rough approximation of the mineral composition as follows: —

Feldspars	65.0
Pyroxene, Hornblendes, etc.	30.0
Accessories	5.0
	100.00

Although less feldspathic and richer in pyroxene, etc. than the average of the rhombenporphyry, the xenolith is more siliceous owing to the greater amount of silica called for by the albite and by the soda-pyroxenes and hornblendes.

It is easy to trace with the microscope the gradual change from the moderately porphyritic type of rhombenporphyry, which is developed in the larger masses near the slate, with only the colorless or pale brown augite, through types, occurring as smaller masses down to those comparable in size with the average xenolith, in which pyroxene of the green, sodic type becomes more and more abundant, in which sodic-hornblende becomes also gradually more abundant and in which quartz may appear sporadically, to a type like the one analyzed. From this we pass with increase of silica, decrease of iron and lime, into types which resemble closely some phases of the granite porphyry of the lower and thinner contact zones.

Turning now to the quartzose and aegirite rich xenoliths we may note that in contrast with its enclosing granite (No. 3) that it is lower in silica, and that the iron is lower and nearly all ferric, as would be expected from the presence of aegirite alone without the ferrous-iron bearing hornblendes found in the granite.

The more siliceous, finely granitic and slightly or non-porphyritic xenoliths are often almost the exact counterparts of some of the fine-granite of the contact zones, others seem to depart somewhat from this type. But as has been pointed out, the fine-granite from different localities (different parts of the contact zone) varies somewhat in composition, and it is probably true that there is a close resemblance between the members of these types and the various fine-granites of

the contact zone. For example, while the xenolith analyzed (17) differs sharply from the fine-granite of the Ruggles Creek type in having aegirite instead of riebeckite, it does bear a very close resemblance in this respect, as well as others, to the fine-granite and granite-porphyry covering the coarse granite with its pegmatite dikes on the knoll just east of the R. R. track, N. E. of the Pine Hill area. If we disregard minor variations, the resemblances, of the porphyritic xenoliths to the rhombenporphyry and to various phases of the granite- and quartz-feldspar-porphyry characteristic of different parts of the contact zone on the one hand, and that of the finely granitic feebly- or non-porphyritic xenoliths to the fine-granites on the other hand, are striking and have an important bearing on the origin of the xenoliths as a whole.

The Aporhyolite.

Distribution.— This rock has a relatively large development in the area. It occurs in at least three separate masses (see general map), which collectively cover several square miles. The first and largest occupies the southwestern part of the Pine Hill tract, and may be connected with the large area of aporhyolite which occurs within the Blue Hill Reservation lying to the south of Rattlesnake Hill, extending southward to the borders of the Reservation where it is lost beneath the great swamp in northern Braintree. According to Professor Crosby it again appears at one point beyond the southern border of the swamp. The area covered by this occurrence is certainly not less than two square miles. The second mass in size is that found lying to the north and northwest of Fox Hill. The third is a relatively smaller mass occupying a portion of the top of Hemingway Hill.

The Pine Hill aporhyolite (see special map) begins a few hundred feet east of the summit of the hill. It here forms a nearly north-south contact with the porphyry phase of the granite intrusion for about fifty feet. The supposed apophysis of aporhyolite described by Crosby as cutting across the contact-porphyry at this point, appears on microscopic study to be in reality only the very fine (felsitic), extreme contact phase of the porphyry, the contact here being irregular in direction for several feet. From the north-south contact just referred to, the aporhyolite mass extends to the west, and broadening out, one contact runs in a west-southwesterly direction for a few hundred feet when it is entirely lost beneath a heavy mantle of drift, but ledges of the rock extend continuously nearly to Willard Street. The other,

and northern contact, is beautifully exposed and runs in a nearly east-west direction to a point a little northeast of the summit. Up to this point, as along the southern contact, aporhyolite is continuously bordered by the coarsely porphyritic and relatively thin zone of quartz-feldspar- and granite-porphyry (with xenoliths of rhomben-porphyry type) earlier described in detail as characteristic of the deeper contact levels. The immediate contact of the two is often very difficult to make out and thin sections are often required to really certainly distinguish the two rocks at the contact. As noted, the porphyry, is at the immediate contact, very dense and feebly porphyritic besides being characterized by breccia and flow structures and gives on megascopic examination alone, the impression that it belongs rather to the aporhyolite than to the porphyry. As can be seen by referring to the special map of this area, the trend of the contact at a point northeast of the summit is irregular, and finally takes a sharp turn to the southwest running along the western base of the hill. The contour of this mass is clearly most irregular. The contact is usually steeply inclined so far as can be told. At one point near the extreme eastern end of the mass it is clearly exposed on a steep cliff marking the western wall of a small valley, and the contact porphyry can here be seen undercutting the aporhyolite with a dip to the south of about 45 degrees.

Whether the aporhyolite on Pine Hill is actually connected with that within the reservation to the west cannot be told, owing to the rather deep, drift filled valley that intervenes. It is probable, as suggested by Crosby that this valley was once occupied, in large part at least, by slate which was eroded away much more easily than the igneous rocks. Contact with the porphyry is found again south of Rattlesnake Hill and can be traced in a westerly direction across the northern slopes of Wampatuck Hill, thence in a gentle curve around the western top of this hill and back along its steep southern face. South of this last line of contact, on the low prominent ledges lying immediately south of the main hill, granite porphyry appears again and extends nearly to the road where it is in contact with the aporhyolite again. The low, rounded knolls that occur directly south and southeast of the road at this point, consist in part of quartz-feldspar porphyry or granite-porphyry, and in part of aporhyolite with characteristic contacts exposed in several places. These are the "islands of quartz-porphyry" referred to by Professor Crosby in his report. Beyond these "islands" to the south, the aporhyolite, so far as can be determined, extends continuously to the borders of the Blue Hill Reservation and probably beyond.

The second, and next most important occurrence begins, as can be seen from the general map, at a point a little north of Fox Hill and runs in a southwesterly direction with a width of at least 500 feet for one-half mile, or as far as Cedar Rock. Beyond this point a heavy mantle of drift makes it impossible to say positively whether it extends further in this direction or not, but it probably does, since as Professor Crosby has pointed out, outcrops of the same rock occur further west beyond Randolph Avenue. The southern and more elevated contact with the porphyry is exposed at several points and it appears to be a nearly straight line with minor irregularities. The northern contact is unfortunately unsatisfactory. At one point Professor Crosby states that it is in igneous contact with slate, but the extremely altered condition of the exposures renders their study of little value. The changes in the porphyry along the southern contact are, as has been noted earlier, more suggestive of the contacts exposed at the eastern end of the Pine Hill mass than that about Wampatuck Hill, although the coarsening of the porphyry is not so marked. As the granite is exposed only a very short distance north of what must be the northern contact of the aporhyolite near its eastern end, the intervening porphyry zone must be a thin one. From these facts, and from the generally massive character of this mass of aporhyolite, it is thought that the southern and more elevated contact represents a deeper zone than that exposed about Wampatuck, but more elevated than that on the eastern side of Pine Hill; and also that if the contact was exposed along the northern side it would be like that east of Pine Hill, just as in the adjoining Pine Tree Brook area the slate contacts are the same in character as those in the northern part of the Pine Hill tract, viz., of the deeper level type.

The third mass of aporhyolite occupies the northern top of Hemingway Hill, as shown on the map. It is an elongated mass of no great width and shows the same contact phenomena with the porphyry as those found about Wampatuck Hill, except that there is perhaps rather more brecciation of the porphyry, particularly near the northern end of the hill. A marked flow structure with taxitic structure characterizes a part of the exposed portions and the rock generally appears like that on Wampatuck and Pine Hill.

Megascopic characters.— The prevailing color of the aporhyolite is a dark reddish-brown or purple. Locally, where it has suffered from strong surface weathering, it becomes whitish with brown rust spots. In places it is an almost perfectly dense, structureless rock though it usually shows a few small rectangular feldspar phenocrysts and less

abundant minute quartz blebs. Locally the porphyritic texture becomes more prominent. Flow structures are common and in certain localities, such as on the top and northern slopes of Pine and Wampatuck Hill, and on the top of Hemingway Hill, the flow structure is very strongly and beautifully developed. Taxitic structures are common, especially where the flow structures are most in evidence. Spherulitic textures may also be seen in many places, but the latter is not a striking megascopic characteristic. Under the hammer the rock is tough and breaks with a sub-concoidal fracture. It is finely jointed, breaking up into small, angular, prismatic blocks. Along many joints and fracture lines, quartz or calcite, or both have been deposited. The large mass of aporhyolite lying northwest of Fox Hill is more uniform and massive than the other occurrences and shows little of the flow and taxitic structures.

Microscopic characters.— Microscopically the rock shows no unusual features for this class of rocks and a brief description will suffice. Thin-sections and the chemical composition show conclusively that the aporhyolite belongs to the same series as the granite, etc. Phenocrysts are few and irregular in distribution, feldspar predominates, quartz appearing only in the form of minute grains. The feldspar phenocrysts are as a rule, when not broken mechanically, fairly sharp in outline, and of a square or rectangular form. The large ones may measure as much as $2\frac{1}{2}$ mm. on a side but are usually considerably smaller. They now consist entirely of a fine microperthite verging toward cryptoperthite in places. They are often fractured and broken apart. The quartz phenocrysts, when they occur, are small and are apt to be rounded or irregular. They do not show marked resorption. No dark silicates are developed as phenocrysts, and in fact these are missing from the rock as a whole. The body of the rock shows considerable variation in texture. No part of it is now glassy, but much of it is so fine as to appear isotropic with low magnifications and it is only with very high powers and strong light that it is seen to be entirely crystalline. The greater part of the aporhyolite is a fine, variously textured mixture of alkalic feldspar and quartz. Most of the feldspar appears to be microperthitic although distinct albite laths can often be detected. Through this mass is everywhere sprinkled, more or less irregularly, tiny grains of hematite and magnetite, the latter commonly showing sharp octahedral outlines. The other alteration products are, kaolin, serecite, calcite, siderite and limonite.

Spherulites made up of segments of finely fibrous quartz and feldspar

are common. They may be scattered through the mass or they may make up almost the entire field, again they are arranged in bands. The spherulites contain abundant grains of hematite or magnetite, or both, arranged parallel to the radiation, and the same minerals are often thickly clustered about the margins of the spherulite. In plane light one can detect the presence of a spherulite by means of these little rayed clusters of iron-oxide grains. Again the rock may be largely made up of alternating bands of a fine irregular mixture of the quartz and feldspar and of a material similar in structure to the segments of the spherulites. The phenocrysts are often included in these bands and hence follow flow lines through the rock. It seems doubtful if the soda-iron silicates ever developed in the rock as originally solidified nor did they form on devitrification, but iron oxides and silica separated instead. In some sections examined, a few minute grains having the appearance of a hornblende, and a few tiny specks of what is thought to be biotite have been noted, but these are probably secondary.

In some parts of the aporhyolite, micropoikilitic structures are developed. These are especially strong in much of the rock from the large mass lying northwest of Fox Hill, which, as has been noted, is of a more massive character generally than the rest of the aporhyolite. Over considerable areas of this occurrence the rock consists almost entirely of a groundmass of micropoikilitic material enclosing fairly numerous phenocrysts of microperthite. The micropoikilitic material forms small roundish, elliptical or mutually moulded areas, which are of about the same size as the feldspar crystals themselves — that is from a few tenths to two or three millimeters, measured along their greatest dimension. About the boundaries of these, magnetite or hematite is often abundant and the same is sprinkled more or less plentifully throughout the rock. The general effect with low powers and crossed nicols is that of a rather finely granular rock. The micropoikilitic areas appear to consist of an intergrowth of microperthite and quartz with a sufficient uniformity of orientation to give them individuality. Some unorientated crystals of feldspar and quartz are scattered through them.

It is perhaps worthy of note that in some of the altered types of the aporhyolite, siderite in tiny rhombohedra and irregular grains and masses is sometimes quite abundant. The same mineral has been seen, or strongly suspected, in the granite, identified in the porphyry, and has been also found in some of the xenoliths in the granite. The presence of this mineral as an alteration product is not common in

igneous rocks so far as the writer is informed. In the present series of rocks its presence is perhaps not remarkable because lime, to form the more usual calcite, is present in very small amount, while iron oxide is relatively abundant.

To determine the chemical composition of the aporhyolite a specimen of rock showing a few small feldspar phenocrysts was secured from some fresh excavations made along the road just south of Wampatuck Hill. The results of an analysis of this specimen yielded the results given below (18). With it are given the results (19) of some determinations made for Professor Crosby by students and also analyses of aporhyolite (11 & 20) from the nearby Neponset Valley intrusion.

	18		19	11	20
	Per cent	Molc. Ratios			
SiO_2	76.37	1.273	74.52	76.52	75.46
Al_2O_3	12.15	.119	13.95	12.30	13.18
Fe_2O_3	1.65	.010	2.72	.70	.91
FeO	1.06	.014		.56	
MnO	.07	.001		tr	
MgO	.10	.002		.16	.10
CaO	.17	.002		.31	.95
Na_2O	3.64	.058		5.19	6.88
K_2O	4.68	.050		4.58	1.09
H_2O+	.08			.41	.93
H_2O-	.13			.11	
TiO_2	.18	.003		.12	
	100.28			100.96	99.50

Sp. G. of No. 18, at 20°C. = 2.645.

18. Aporhyolite, Wampatuck Hill, Blue Hill Reservation, Mass. Analyst, C. H. Warren.
11. Rhyolitic faces of Neponset Valley, Mass., granite. Analyst, W. H. Hall. F. Bascom, op. cit., p. 138.
19. Average of several determinations quoted by Crosby (op. cit., p. 380) of aporhyolite from Pine Hill.
20. Aporhyolite (flow) Neponset Valley, Mass. Analyst, W. H. Walker. F. Bascom, op. cit., p. 144.

The aporhyolite (18) is more acid than the granite or its contact facies, the total iron lower and the potash relatively higher. The averages given by Crosby (No. 19) of the rock from Pine Hill, show lower silica and higher alumina. Variation is probably to be expected in different parts of a rock of this character. Devitrification and the attendant alteration have undoubtedly modified the rock as a whole and the true composition of the rock as originally solidified cannot now be determined. But there is no doubt whatever of its belonging to the Quincy type of magma.

The norm is as follows: —

Quartz	36.84	$\frac{Sal}{Fem} = 2.0$. Class I. Persalane.
Orthoclase	27.80	95.49 Salics.
Albite	30.39	
Anorthite	.56	$\frac{Q}{F} = 0.6$. Order 3. Quarfelic.
Corundum	.92	$\frac{K_2O+Na_2O}{CaO} = 54$. Range 1. Peralkalic.
Hypersthene	.86	
Magnetite	2.32	4.56 Femics.
Ilmenite	.46	$\frac{K_2O}{Na_2O} = .86$. Subrange 3. Sodipotassic.

The rock is, therefore, an alaskose and may be termed a granialaskose. The mode is essentially like the norm. The ratio of Ab: Or is 1.09 that of the granite 1.02; or Ab, 52.3; Or, 47.7, the granite Ab, 50.5; Or, 49.5.

In columns 11 and 19 are given the compositions of the rhyolitic rocks associated with the neighboring Neponset Valley granite intrusion. They show the characteristic differences of the two magmas, viz. higher iron and predominance of potash over soda in the Quincy magma, whereas soda dominates, sometimes greatly, over potash in the Neponset rocks. Thus the chemical evidence agrees entirely with the microscopic, in showing that the Blue Hill aporhyolite belongs to the Quincy granite magma and is quite distinct from the abundant volcanics developed in the neighboring areas of granitic rocks.

Slate-Granite Contacts, North Common Hill, Quincy.

The contacts of the coarse-granite with the slate along the northern side of North Common Hill, Quincy, show no intermediate contact phases and therefore call for special mention. As pointed out by Crosby [44] there are numerous patches of slate lying in the coarse granite.

44 loc. cit., p. 28 et seq., also special map opp. p. 428.

Some of these have a length of nearly one hundred feet by somewhat less in width and are stated by Crosby to show a very constant strike of N. 80 E. with a dip, S. 80–85, the metamorphism by the granite not having been sufficient to obliterate the true bedding of the slate. This constant orientation of isolated pieces of the slate is held by Professor Crosby to indicate that they are — "roots of a once continuous body of slate."

The granite remains coarse up to within an inch of the slate and then is fine-grained to the contact, nor was the granite necessarily rendered finer because of chilling, but may have developed simply a finer grain induced by direct physical contact with the slate surfaces. The slate is very dense, hard, and somewhat, though not very highly, metamorphosed, and shows no evidences of having received any additions from the magma with which it was in contact. The absence of extreme metamorphism certainly does not argue in favor of any excess of heat nor of volatile products in this part of the magma, a point that is of importance in any consideration relating to the method by which the magma came into its present position.

The absence of the contact phases, which are elsewhere developed between the granite and the older rocks, and the present higher elevation of the slate-granite contacts on North Common Hill relative to other parts of the field where the contact phases are strongly developed — Pine Hill for example — makes it necessary to assume, that either these contacts were originally much deeper seated portions of the contact and since have been elevated, or that the slate patches represent sunken blocks frozen in the granite, and that somewhere above the present plane of erosion there once existed a cover of the contact porphyries. The constant orientation of isolated blocks of slates over so considerable an area, and the presence of a well defined fault contact lying but a little way to the north with a probable upthrow of the igneous rocks relative to the sediments [45], points very strongly to the correctness of Crosby's conclusion that the slate here represents remnants of the original slate contacts.

Pegmatite "Pipes."

Three pegmatitic masses having the form of elongated, pipe-like bodies occur in the granite of North Common Hill, Quincy. These are remarkable for their structure and crystallizations and have been made the subject of an extended description by Professor Charles

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45 See G. F. Loughlin, op. cit., p. 29.

Palache and the writer [46] to which reference may be made for details. These pipes lie wholly within the granite, and it is certain that one, and probably two, did not even reach the present eroded surface of the granite. It is thought that they represent relatively siliceous, water-rich segregations formed at greater depths in the magma.

Vein phenomena.

Occasional quartz veins occur in the granite and granite-porphyry. They are generally small affairs measuring from $\frac{1}{4}$ to 1 inch in width but have usually a considerable length and appear to reach deep into the rock. Several of these have been referred to by Dale as occurring in some of the quarries. They usually contain small amounts of fluorite and some of them sphalerite, galena and chalcopyrite. Similar sulphides were noted in the pegmatite pipes.

Dike Phenomena.

As has been noted earlier in the paper, dike phenomena connected with the intrusion of the alkaline rocks are inconspicuous. With the exception of a few small pegmatitic dikes or streaks and of two narrow and short microgranite dikes cutting the granite, the dike phenomena of the area is confined to the few granite dikes cutting the cover-porphyry in the region about Slide and Scamaug Notches, and to those dikelets or apophyses invading the slates for a short distance from the actual contact. These latter have been described and figured in some detail by Professor Crosby and appear to be merely offshoots from the main mass of granite. They are for the most part small affairs though in a few instances they appear to have attained considerable size. Some of the larger ones are of about the same grain as the granite; the smaller ones are quite fine. None of them with the exception of the dikes in the Pine Tree Brook Reservation appear to possess any noteworthy characteristics not fully covered by Crosby's descriptions.

The last mentioned dikes cut the slate and also the only series of diabase dikes which are known to be older than the alkaline rocks of eastern Massachusetts (see special map Pine Tree Brook Area). The slate cover in this area is very thin, in fact, forms hardly more than

[46] These Proceedings, **47**, No. 4 (July, 1911).

a thin skin about and through which the underlying igneous rocks appear constantly. Against the slate, the normal development is first the relatively basic feldspar-porphyry. This is succeeded by a thin zone of granite-porphyry passing into the porphyritic coarse-granite. In places, fine-granite appears to come in as a contact phase as noted earlier. The coarser granite intrudes the fine-granite and both porphyries in many small irregular dikes, and in the extreme western edge of the area, running for about one half of it's length (in part outside the northern boundary of the reservation) is a large dike of variable width and quite irregular trend which has a total length of something over a thousand feet. The width varies from a few feet to as much as 100 at the widest part. Just north of the boundary fence this dike is well exposed for study. Its eastern side, westward from the slate for perhaps ten feet (exposed), consists of a fine-granite-porphyry containing fairly abundant phenocrysts of feldspar and quartz and abundant specky hornblende. The center consists of the porphyritic type of coarser granite in which are embedded a great number of inclusions of the basic feldspar-porphyry of the same composition and character as that found in the massive ledges only a little distance away where the slate cover has been worn away. These inclusions are of all sizes from one-half centimeter to those which will measure two feet across, though the average will not probably exceed seven or eight inches. In shape they are sub-angular, rounded, elliptical or irregular, closely similar in fact to the inclusions described as occurring in the granite of the glaciated ledge of the Pine Hill area, West Quincy (p. 274). Some slate inclusions are also present. Though the western side of the dike is not well exposed, the fine-granite-porphyry appears to form the border of the western contact also. The dike is doubtless a very shallow one, hardly more than an upward protuberance of the invading igneous mass into the slate cover. The composition of this dike is satisfactorily explained if we assume that prior to the intrusion of the dike, the magma beneath the slate had differentiated and partly crystallized with the development of the rhomben-porphyry next to the slate. Pressure from below then caused the magma to burst through the cover of slate above, breaking up the layer of basic feldspar-porphyry and carrying its fragments, together with slate, up into the dike channel mingled with the granitic magma. Toward the margin, the dike assumed a finer grained and porphyritic texture, but centrally crystallized as granite.

Small dikes and patches of pegmatitic character always containing some fine-granite material [47] are found; one on the Rattle Rock;

[47] See Warren & Palache, loc. cit., p. 127.

several on the small hill south of North Common Hill, Quincy, and just east of the northern extension of the Pine Hill Area; and several small dikes and patches of irregular outline in the coarse-granite near its contact with the fine-granite in the old quarry just off Quincy Ave. in Weymouth. In all of these occurrences it is noteworthy that the pegmatitic dikes occur either at the contact with the granite-porphyry (Rattle Rock and northeast of Pine Hill), or with its fine-granite equivalent (Weymouth). Their origin is probably to be found in the filling of fractures in the upper parts of the granite by injection of fluid material from beneath. The banded texture of the larger veins — coarse margins, fine centers, etc.— have been discussed elsewhere.[48]

PART II.

General Discussion.

Chemical and Mineral characters.— Although these characters have been more or less fully discussed under each type it may be well to briefly summarize certain important features brought out by the chemical analyses.

The entire series are characterized by relatively high iron and alkalies, by exceedingly low magnesia and also by almost equally low lime, except in the case of the rhombenporphyry and the rhombenporphyry xenoliths, in both of which the lime reaches about three percent owing to the presence of a lime-iron rich pyroxene probably a hedenbergitic augite.

There is a considerable fluctuation (see table No. I) in the total iron oxide content even between the coarse-granites (compare 1–2 with 3), while the rhombenporphyries show a great difference, compared with the rest, in their high iron content. It is to be noted that there is a strong sympathy between the iron oxides and high alkalies; as the amount of feldspar increases the sodic-iron silicates increase also. The relative amounts of K_2O and Na_2O are not far from equal, with the exception of the rhombenporphyry xenoliths, and this abnormality may point to some later addition of soda from an enclosing hot magma. The potash on the whole slightly predominates in amount.

48 Palache & Warren, op. cit., p. 127.

TABLE NO. I.

	Coarse Granites				Fine Granite	Granite-Porphyry	Rhomben-Porphyry	Rhomben-Porphyry Xenolith	Aporhyolite	Riebeckite Granite. S. Norway	Riebeckite Granite. Kamerum	Riebeckite Granite. Socotra	Biotite Hornblende Granite. Neponset, Mass.
	1	2	3	5	10	13	15	16	18	6	7	8	9
$Al_2O_3 + Fe_2O_3$ =	.128	.121	.137	.137	.136	.133	.169	.163	.129	.145	.165	.110	.149
$Na_2O + K_2O$ =	.117	.114	.124	.125	.127	.123	.129	.135	.108	.145	.153	.100	.118
Ratio $\frac{R_2O_3}{R_2O}$ =	1.09	1.06	1.10	1.09	1.07	1.08	1.31	1.20	1.19	1.00	1.07	1.10	1.26
Average of 1 to 13 inclusive = 1.08; average of 6–7–8 = 1.05.													
Na_2O =	4.21	4.03	4.66	4.61	4.59	4.43	4.47	5.64	3.64				
K_2O =	4.62	4.68	4.63	4.79	5.00	4.90	5.29	4.26	4.68				
Total	8.83	8.71	9.29	9.40	9.59	9.33	9.76	9.90	8.32				
Ratio $\frac{K_2O}{Na_2O}$ =	1.10-	1.16	0.99	1.04	1.09	1.10	1.16	.75	1.01	Contact Phases Granite-Porphyry			
Fe_2O_3 =	2.25	1.71	2.91	2.77	1.75	1.67	2.33	2.80	1.65	2.18	2.67		
Fe O =	.93	1.26	1.55	1.09	2.33	2.10	6.03	6.57	1.06	1.71	1.52		
Total =	3.18	2.97	4.46	3.86	4.08	3.77	8.36	9.37	2.71	3.89	4.19		

A study of the ratios existing between the sum of the molecular proportions of alumina and ferric oxide, to that of the soda and potash reveals a high degree constancy if we except the rhombenporphyry phases (15 & 16 Table No. I). Inasmuch as no allowance has been made for magnetite nor the small amounts of lime and ferrous-iron which, of course, effect this ratio, some variation is to be expected. The departure from constancy in the rhombenporphyries is caused by the larger amounts of lime and ferrous iron, whose relations cannot be very precisely determined, but the direction of the divergence is the one to be expected.

Another point of considerable interest is the proportions of the soda and potash feldspar molecules present in the microperthite resp. cryptoperthite or soda-orthoclase. These proportions are shown in Table No. II as calculated from the analyses: —

TABLE NO. II.

		Quincy Granite	Fine Granite	Granite Porphyry	Rhomben-Porphyry	Aporhyolite	Average	Vogt's[49] Anchi Eutectic Feldspar
		4	10	13	15	18		
Quartz % in rock		33.3	23.3	26.7				
Albite % in rock	=	28.1	36.9	34.8	40.2	30.4		
Microcline % in rock	=	27.5	29.5	29.0	31.1	27.8		
Microperthite resp. Cryptoperthite, Soda-orthoclase	=	55.6	66.4	63.8	71.3	58.2		
Ratio $\frac{Ab}{Mic}$	=	1.02	1.25	1.20	1.29	1.09	1.17	1.27 to 1.50
Albite %	=	50.5	55.6	54.5	65.3	52.3	53.8	56 to 60
Microcline %	=	49.5	44.4	45.5	43.7	47.7	46.2	44 to 40

There is, in spite of a rather large fluctuation in the total amounts of the two feldspar molecules, a rough approximation toward a constancy in their relative proportions, but the ratio is lower than the lower limit for feldspar intergrowths as estimated by Vogt. In calculating the Ab: Mic. ratio several assumptions had to be made which would obviously affect the ratio so that they are at best only approximations.

49 Tschermak's Mineral. u. Petrog. Mitt. Vol. XXIV, No. 6, 1906, p.

However, had it been assumed that the albite was as sodic as $Ab_{98}An_2$ instead of $Ab_{95}An_5$, the ratio would, for the average of the granites (No. 4), been only 1.21 at most, and this would have reduced the aegirite and hornblende percentages considerably below their true value and raised the magnetite above a probable value. A similar change in the albite, would in the case of the fine-granite, affect the ratio very little since this was controlled by a quantitative, microscopic estimate of the minerals present, and this ratio also falls just below Vogt's minimum. The Quincy rhombenporphyry, however, does fall within it. Despite the possible errors (at least these are perhaps no greater than enter into Vogt's admittedly approximate estimates) in such calculations where some assumptions have to be made, and where slight changes in the Na_2O values used cause much greater changes in the resulting minerals, the writer believes that the values given are worthy of some weight and indicate a wider fluctuation in the proportions of soda to potash feldspar in their intergrowths than those estimated by Vogt. It is also to be noted that a small portion of the albite occurs in these rocks outside of the intergrowth. This is included in the above calculations because of the impossibility of estimating its amount, but if allowances for it could be made it would have the effect of still further lowering the proportion of albite that is present in the intergrowth with the microcline.

The relative proportions of quartz to feldspar are also interesting. Table II, p. 296, shows that these are, when calculated to 100%:— 37.4%, quartz to 62.6%, feldspar in the coarse-granite; 25.9% to 74.9% in the fine-granite and 29.5% to 70.5% in the granite-porphyry. Although there is admittedly some chance of error in the calculation of these percentages, the writer believes that the possible error is not sufficient to account for the considerable differences shown by these figures and that they represent real differences of composition. While the fine-granite and granite-porphyry are not so far apart, the coarse-granite shows a wide divergence. Dispite the probability that the considerable amounts of sodic-iron silicates present in the rocks might effect the composition of a possible quartz-feldspar eutectic as compared with purer quartz-feldspar granites by an amount impossible to estimate at present, it is interesting to note that the figures for the fine-granite fall on one side of the ratio for the "granite eutectic" as estimated by Vogt [50] and the granite-porphyry on the other side. Vogt's estimate is quartz, 27.5% feldspar, 72.5%. The coarse-granite

50 Tscherm. Min. Pet. Mitth. (2), **25**, pp. 361–2, 383–5 (1906).

departs very widely from this figure, whereas it is the latter that should correspond most nearly to the eutectic composition on the basis of the theory. It is of course by no means necessary, in a magma representing, like the present one, a very complicated chemical system in which there are certainly a considerable number of as yet imperfectly understood solid-solution relations existing between the various components, that the end product of differentiation should be a eutectic mixture. In any case the figures above given serve to illustrate the present uncertainties of the eutectic theory as applied to such systems.

Fluorine is present usually in small amount: locally near quartz veins, in the pegmatitic pipes, and in certain contact facies of the porphyry cover it is quite abundant in the form of fluorite, which is its usual mode of combination. Small amounts are present in the riebeckitic hornblende, and in the pegmatite pipes it is also present in the mineral parasite. Zirconia is generally present in small amount as zircon. Titanium is present in ilmenite, aenigmatite, astrophyllite, titanite (in part or wholly secondary) and probably to a small extent in the hornblende. The cerium earths make their appearance in the parasite of the Pegmatites and are doubtless present elsewhere in the granites, etc. Though very small in amount their presence is interesting and is probably, like zirconia, characteristic of this type of rock. Traces of molybdenium (as molybdenite), lead (galena), zinc (sphalerite) are present in the magma since they are found in the quartz veins and pegmatitic phases.

Although it is the writer's opinion that the greater part of the original mineralizers were retained within the granite by the quick chilling of the upper zones, these acting as a protecting cover, it is possible, if not indeed probable, that the more volatile contents of the extreme upper portions of the invading magma were in great part lost by rapid and easy diffusion through the relatively thin cover of sediments. The occasional strong development of fluorite in certain localities where the indications are, that the rock as now exposed was originally not far removed from an original contact, supports this view. The retention of mineralizers in the magma appears to be a characteristic feature of other occurrences of this type of rock, particularly that of Dobrogea on the Danube which seems to resemble the present occurrence in many respects.[51]

The riebeckite of the fine-granite appears to correspond closely to

[51] Murgoci, op. cit., pp. 142–144.

that of the pegmatite pipes which have been analyzed and shown to consist essentially of such molecules as $Na_2Fe_2Si_4O_{12}$, $(R''_1R'_2)\ Fe_2Si_4O_{12}$, where R'' equals chiefly Fe'' and R', soda, but with small amounts of fluorine and hydroxyl water. Doubtless the riebeckite of the coarse-granite is in large part closely similar, but it appears to pass easily into an alkali-iron hornblende closely allied to the catoforites. The aegirite of the pegmatite pipes consists of the almost pure aegirite molecule $Na_2Fe_2Si_4O_{12}$ and much of the aegirite of the granite is doubtless of the same pure variety, but in the earlier formed pyroxene noted, though for the most part rich in aegirite compound, other molecules enter, chiefly one rich in calcium and iron. This molecule appears also as important in the early pyroxene of the rhomben- and granite-porphyry. Again in the granite and granite-porphyry we have aenigmatite or some closely allied species appearing. All this illustrates well the great complexity of the relationships existing between these soda-iron rich minerals. There are doubtless a number of solid-solution relationships, complicated by polymorphism, concerned in their growth. The formation of one or the other is doubtless effected by the presence of mineralizers, principally fluorine, by differences of pressure and rate of cooling, but of all these things we have at present such wholly inadequate information that speculation regarding the thermo-chemical relations of these minerals seems too uncertain to be worth venturing further with at present, and such conclusions as those arrived at by Murgoci [52] regarding the formation of riebeckite and aegirite, interesting and suggestive though they are, must be held open to much question.[53]

The intrusion of the Batholith.— The facts developed by the present investigation are obviously too meagre so far as their bearing on the general question of igneous intrusion is concerned to warrant a lengthy discussion of this problem. As bearing on the problem of the intrusion of this particular mass of rock they are believed to be instructive and fairly complete, and it is hoped that a brief discussion of this particular problem may add a little of value to the more general one.

There is, the writer believes, convincing evidence [54] that before the

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52 American Journal of Sciences, **20**, No. 116, (Aug., 1905).

53 See also in this connection Warren & Palache, op. cit., p. 144.

54 The evidence is not direct, so far as the pre-Cambrian sediments and granites are concerned, since the Quincy rocks are nowhere found in igneous contact with these rocks. Both to the north in Essex Co., and to the south in northern Rhode Island, there are intrusions of alkaline granites so similar to the Quincy that there can be no doubt that they are of the same age. These are known to cut an older, biotite granite. Their intrusion was preceded,

intrusion, the space now occupied by the alkaline rocks was formerly filled by Cambrian and pre-Cambrian sediments, and probably also in part by an older biotite granite intrusive into at least a part of these. Whatever the exact manner in which these older rocks were replaced by the batholith [55] these certainly had no appreciable effect on the chemical composition of the batholith as now exposed by erosion and quarrying. The Cambrian sediments now extant in contact with the batholith or in its neighborhood, nor the pre-Cambrian rocks existing in nearby areas, could not, by any process of assimilation, produce the present highly specialized chemical character of the batholith unless such assimilation were accompanied by a drastic differentiation which it is quite certain has not taken place in the batholith as exposed. That the magma of the present batholith was originally produced at greater depths by the differentiation of a magma which had during some past epoch assimilated older rocks, is not denied, indeed, the writer believes that such a process did take place. The assimilation of any noteworthy quantity of sediments and subsequent differentiation demands an enormous amount of heat, or a long continued period of sufficient heat to ensure the necessary mobility, which does not appear to have been the case in this magma. This is shown by the lack of extreme metamorphism of the Cambrian slates found at the contacts, even of the coarse granite on North Common Hill, Quincy, which must represent relatively deep portions of the original contact, as has already been pointed out. There is for example much less metamorphism in these sediments than that described by V. M. Goldsmidt [56] for the sediments in contact with, or included in,

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at least in Essex Co., by acid alkaline intrusive and effusive rocks which either lie upon an eroded surface of the older granite, etc. or cut them. The bulk of the evidence referred to is contained in the unpublished thesis of Dr. C. H. Clapp (Thesis for the degree of Doctor of Philosophy in Geology, C. H. Clapp, Mass. Inst. of Technology, Boston, Mass., 1911.) An abstract of this thesis has been published setting forth the main results and a paper will appear later as a bulletin of the U. S. Geological Survey. The facts regarding the alkaline granite in Rhode Island will be published by the writer and Mr. Sidney Powers in a future paper now in preparation.

55 Although the mass of alkaline rocks exposed is not large, perhaps not large enough to warrant the use of the word batholith according to the ideas of some geologists, the writer has used it as a convenient term. In all probability the mass is connected with a much greater mass of alkaline rock beneath, which has sent up protuberances as it were, of which the Quincy-Blue Hill mass is one, the Rockport, Mass. Granite another, and those near Diamond Hill, Rhode Island another. There is no evidence whatever of anything in the nature of a laccolith about the Quincy-Blue Hill mass.

56 Videnskapsselskapeta Schrifter, **1**, Mat. Naturv. Klasse, No. 1 (1911).

the igneous rocks of the Christiania region where no chemical assimilation in place has taken place in the opinion of the workers in that field. The relatively thick cover of porphyry, representing as it does the chilled upper portion of the invading mass, which covered a great part of the batholith, is itself another strong evidence that there was not enough original heat, or that the solidification took place so near the surface that the magmatic heat was too rapidly dissipated, even to keep the temperature sufficiently high for a sufficiently long interval to permit of the assumption of a plutonic texture throughout. No differentiation to amount to anything appears to have occurred in either the fine-granite nor the granite-porphyry, excepting in the thin zone of porphyry found for a short distance along the aporhyolite contact on Pine Hill and at the slate-granite contacts in the Pine Tree Brook area. It is only along the deeper contact levels such as represented the two areas just mentioned, or in the granite directly under its own porphyry cover, where the magma remained hot and permitted differentiation to take place, that we find evidences of differentiation. Furthermore, complementary dike phenomena, either in the granite or in the adjoining country rocks, are wholly wanting and this is thought to be further evidence that extensive differentiation did not take place. It is believed that such as did occur can now be seen in large part, at least, in the batholith as it stands today. If these deductions are correct the production of the magma by the actual melting of the sediments as proposed and set forth at length by Professor Crosby in his report on the region, is out of the question.

That the magma took the place of large volumes of pre-existing rock is certain, and that it did so without appreciably effecting the chemical composition of the magma appears almost equally certain. To accomplish this only two methods of intrusion appear possible to the writer. The first, is that the magma actually pushed up a great block of rock (bysmalithic) thus bringing it up to its present level, which was so near the surface that the magma became chilled so that little differentiation could take place and the heavy mantle of porphyry was developed as a chilled cover. It is certain that the alkaline rocks have suffered some differential movement and that they have been tilted up, relatively at the north. These movements took place along great major fault lines and it is perhaps possible that these may represent lines of weakness along the original lateral contacts of a bysmalithic intrusion. This hypothesis would do away with many grave difficulties but there is no proof whatever. The other possible method of intrusion which offers an explanation of the

facts as presented is, that of "stoping" as advanced by R. A. Daly [57] and in a somewhat less highly developed form, independently, by J. Barrell.[58] If the Quincy magma has reached its present position by replacement and not by displacement of the country rock, and has not dissolved the invaded rocks, then the writer can see no escape from the so-called stoping method of replacement.

The first solidified portions of the magma are found in place in several parts of the field. In eastern and southern Quincy and northern Weymouth we find the fine-granite as the contact phase. Considerable portions of this were broken up or invaded by the still fluid magma beneath, as shown by the perfectly sharp igneous contacts of many of the larger masses of fine-granite with the coarse, by the included masses of fine-granite and by the dikes of coarse-granite cutting the fine. This part of the area undoubtedly represents relatively deep levels of the contact (as held by Professor Crosby). In the Pine Hill tract and the Pine Tree Brook reservation the contact-porphyry is a relatively thin zone passing gradually and rapidly into granite and here also are found the basic marginal differentiate of the magma, the rhombenporphyry, and also the other phase of lower contact levels, the fine-granite. In both areas there is positive evidence of the movement of the underlying magma, which often resulted in a breaking up of the earlier consolidated rocks or in invasion of them by dikes, or both. In the Blue Hill Reservation proper, where the cover-porphyry attained a great thickness, the transition from the granite-porphyry to the porphyritic phase of the coarse-granite is either very rapid, or as observed on Rattlesnake Hill, the contact is sharp, indicating that there the magma moved under its own cover. Again in and about Slide Notch we find actual dikes of granite (with xenoliths of the dark feldspar-porphyry and fine-granite types) of considerable dimensions cutting the porphyry cover. In several places among the higher hills we have also noted the occurrence of considerable areas of fine, feldspar-quartz-porphyry essentially identical with the contact phases (against the aporhyolite of Wampatuck Hill for example) of the granite-porphyry, but in many instances, as for example, on the northern and northeastern slopes of the Great Blue Hill, the contacts of these fine porphyries and the associated granite-porphyry are either very rapid transitions or are really sharp though perfectly sealed contacts, again indicating a movement accompanied by breaking off,

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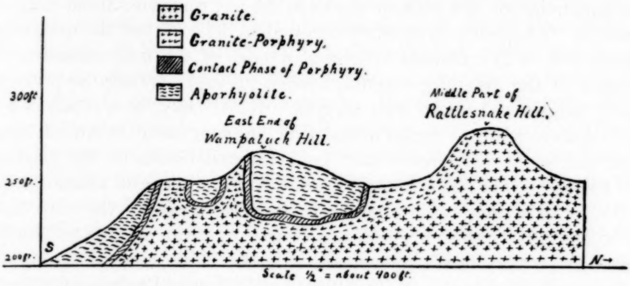
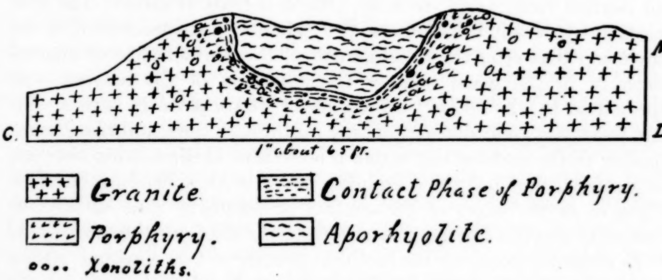
[57] American Journal of Science, No. (1903) **26**, (July, 1908).
[58] U. S. Geol. Surv., Prof. Paper, No. 57; (1907).



SECTION THROUGH RATTLESNAKE AND WAMPATUCK HILLS, BLUE HILLS.

This section, drawn approximately to scale, is taken through the eastern and lower end of Wampatuck Hill and the central portion of Rattlesnake Hill and is intended to illustrate the writer's conception of the relations existing between the aporhyolite, contact-porphyry, granite-porphyry etc. The actual width of the chilled contact zone immediately against the aporhyolite is exaggerated in order to show it on this scale diagram.



SECTION THROUGH THE APORHYOLITE-PORPHYRY CONTACT EAST OF PINE HILL, WEST QUINCY.

This section, drawn approximately to scale, illustrates the relation, as worked out by the writer, existing between the aporhyolite, granite-porphyry etc. along those portions of the contact between these rocks found at relatively deeper levels than that shown in the Rattlesnake Hill section. Here the very dense immediate contact rock is succeeded by a narrow zone of coarsely and profusely porphyritic rock which in turn passes gradually, but rapidly, through granite-porphyry into the porphyritic phase of the coarse granite. Flow structures are strongly developed near the contact, and dark colored xenoliths are found in the coarsely porphyritic phase and also in the granite-porphyry and granite somewhat more distant from the contact.

and immersion of, the broken blocks in the yet unconsolidated magma beneath. The writer is strongly inclined to believe that the masses of aporhyolite in like manner represent masses of the first consolidated portions of the invading magma, broken up and partially or perhaps wholly immersed in their own magma. R. A. Daly, as a result of his acquaintance with the region in question, has suggested tentatively that these masses of aporhyolite may be foundered blocks of the original roof rocks.[59] The fuller knowledge of the characters and relationships of the rocks of the region which we now have, supports the view that the aporhyolite represents portions of the invading magma originally consolidated very near the surface, at least. This view of the origin of the aporhyolite brings us into direct opposition to Professor Crosby's conclusions and the question of its relative age must be examined more in detail. The characteristics of the porphyry at the contact with the aporhyolite have been described and shown to be everywhere indicative of a chilled contact and this fact was fully recognized by Crosby. He offered two hypotheses as to the nature of the aporhyolite. First, that it is in the main truly intrusive through successive zones of the batholith and interformational with reference to the slate and contact rocks; and secondly, that it is truly effusive. The first as stated by Crosby is as follows:[60] "Hence we seemed forced to the conclusion that after the development of the contact zone of quartz-porphyry in the usual manner the extrusion of the magma now represented by the felsite" (aporhyolite) "took place in such a way as to form, not great dikes extending up through the Cambrian strata, possibly to the surface, but rather a laccolithic accumulation between the contact zone and the Cambrian cover, with a bending down or falling in of the edges of the contact or porphyry zone sufficiently marked to account for the great width of the dike, for the narrowness of the porphyry zone, for the fact that in spite of very unequal erosion the felsite is nowhere found in contact with the granite, and for the high inclination of the felsite-porphyry contact. . . ." "A sill[61] extending south from a laccolithic trough between the contact zone of the batholith and its Cambrian cover would, perhaps, best express the idea."

The second hypothesis, and the one favored by Crosby, is stated by him as follows:[62] — . . . . "the felsite is truly effusive, post-dating. . . .

[59] These Proceedings, **47**, No. 3, p. 62 (June, 1911).
[60] op. cit., p. 386.
[61] op. cit., p. 387.
[62] op. cit., p. 387.

the erosion requisite to lay bare the batholith, and occupying in its broader, dike-like development between the east side of Pine Hill and the summit of Wampatuck Hill, a steep-walled valley due to the erosion of a deeply included body of slate. Depressions having this origin exist in the modern topography, the valley of Ruggles Creek being a good example. If now, we conceive such an erosion trough, with its wall of quartz-porphyry essentially intact, as the Ruggles Creek Valley is today bordered by the contact zone of fine-granite, to be traversed longitudinally by a fault fissure with a down-throw to the south, as the valley of Ruggles Creek unquestionably is, the outflow of acid lava filling the depression and connecting fissure, and flowing out away to the south, would seem to account for all the facts as they are now developed in the field."

Under the first view it seems to the writer very difficult to conceive of a magma forcing its way in between the contact porphyry and its slate cover in such a way as to carefully remove all of the slate over a great area of what was certainly a most uneven contact surface without leaving, so far as known, a single fragment of it between the porphyry and the aporhyolite.[63] Under the second view, it seems very unlikely that erosion, accompanied by even the most favorably disposed faulting, could have removed the slate cover *just so* far as the fine-grained contact phase of the porphyry *and no farther*, for the aporhyolite *never* comes in contact with any other phase of the batholithic rocks; and this over a wide area, at various elevations and along a most devious line of contact. Furthermore, it would seem almost inevitable under either hypothesis that the lava would have included within itself fragments of either the slate or the porphyry, or both, and such inclusions are nowhere to be found, at least along the great length of contacts which have been examined by the writer. The porphyry at all of its exposed contacts with the aporhyolite bears all the characteristics of a chilled contact phase against *something*, and it appears most natural to assume that the chilling was done by the rock with which it is now in contact — the *aporhyolite*. It is wholly inconceivable that the aporhyolite itself, a rock, that in large

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63 It should be noted that the aporphyolite is in contact, according to Crosby, with slate northwest of Fox Hill, but the precise relation of the slate to the nearby granite and porphyries is unknown. The only other slate anywhere near the aporhyolite is a fragment, 2 ft. across, embedded in the granite-porphyry just east of the eastermost, and very narrow end, of the aporhyolite in the Pine Hill area.

part, at least, solidified as a vitreous rock, should have so altered the granite-porphyry as to reproduce in it the characteristic contact structures which it now possesses.

An alternative hypothesis to the one proposed above, viz. that the aporhyolite represents engulfed blocks of the original chilled roof, might be that, the aporhyolite was first intruded, at a distinctly earlier period into the relatively cold slates relatively near the surface, in the form of great dikes, or more irregular masses, or even was extruded, and that later followed the greater invasion of the main mass. In such case the magma would be expected to have enveloped much of the rocks first invaded by the rhyolite along with it, which is certainly not the case. It must be frankly admitted that the view that it is an earlier formed rock is not free from serious difficulties and the conclusion finally reached in any case is perhaps determined by a "choice of evils", and the writer has chosen what appears to him to be the lesser one, namely those which make the aporhyolite an earlier consolidated part of the alkaline intrusion.

Consolidation of the Magma.— From the relationships previously set forth we may conceive of the consolidation of the batholith having taken place somewhat as follows: — at the highest levels, near the surface, sudden chilling resulted in the formation of considerable masses of highly vitreous rock; a little lower down, in the denser forms of the feldspar-quartz-porphyry. These earliest consolidated rocks were fractured and broken off by movements of the fluid mass beneath, large blocks of them became immersed in the magma, perhaps sunk, and against them the magma consolidated with sharp but tightly sealed contacts showing a variable amount of local chilling. Further cooling of the magma, still at relatively high levels, resulted in the formation of a thick zone of feldspar-quartz-porphyry and granite-porphyry. This thick cover of still relatively hot rock, being a poor conductor of heat, acted as an effective blanket, protecting the magma underneath and permitting it to solidify with sufficient slowness to develop a truly granitoid texture. In places, perhaps very generally, the magma beneath this porphyry-cover moved relatively, and sometimes broke through, forming the granite dikes like those noted as occurring in and about Slide Notch. As these dikes contain numerous cognate xenoliths, — rhombenporphyry and fine-granite types — and as these are also found in the granite directly underneath the porphyry, as at Rattlesnake Hill, it appears that the magma, wherever it remained hot and sufficiently fluid for some time, differentiated to a small extent yielding more basic phases, which were more

or less broken up and scattered, itself becoming in consequence slightly more acidic.[64]

At lower levels of the contact, such as those represented by the area located in eastern and southern Quincy and northern Weymouth, the magma first consolidated as the fine-granite against the slate. Here again the contact phase was fractured and to some extent engulfed in the underlying magma as shown by the included blocks, the dikes in the fine-granite and the sharp contacts generally existing between the two granites.

The fine-granite and the granite-porphyry characteristic of the chilled cover at lower and the other at higher levels are, so far as extent and thickness are concerned, by far the most important marginal phases of the batholith, and although they differ sharply as to texture and to some extent in the character of their dark silicates, they are, as we should expect, almost identical in chemical composition. They are both slightly more basic than the average of the coarse-granite. Their textures and the absence of differentiation products in them suggest that, being more quickly cooled, they did not differentiate but solidified with substantially the composition of the magma as intruded, and it is only beneath them, or at deeper contacts against the slates, that the magma differentiated.

At other relatively deep contacts, such as those represented by the Pine Hill and the Pine Tree Brook areas, we find the first formed secretion of the magma against the slate to be the rhombenporphyry, indicative of more considerable differentiation. The rhombenporphyry, like the first formed rocks generally, was broken through by the underlying magma and portions of it are found abundantly distributed through the associated granite and porphyry. The magma on breaking through this early phase, in part consolidated as a thin zone of coarse porphyry, in part as a porphyritic phase of the fine-granite, or as fine-granite. All of these were again broken through by the magma, as shown by the dikes which are so prominent a feature of the Pine Tree Brook area.

An objection might here be raised, that at the granite-slate contacts

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64 The aporhyolite was originally in large part glassy and has since suffered devitrification and alteration so that its exact original chemical composition is in doubt. As it stands, it appears to be on the average about as siliceous as the granite, perhaps slightly more so. This might be held to favor its being of later origin. On the other hand it may well represent a relatively siliceous and originally more aqueous upper portion of the invading magma doubtless closely similar in this respect to much of the fine-grained feldspar-quartz-porphyries of the higher elevations.

found on North Common Hill, which seem to represent the deepest contacts anywhere exposed and which have been brought up to their present relatively high positions by faulting and elevation at the north, no rhombenporphyry is now found at the contact, whereas if it is true, as had been assumed, that it is in places where the magma remained hot for a long period, thus retaining its fluidity and permitting differentiation to take place, it is precisely here that the products of differentiation should be found. In view of the fact that elsewhere in the field the first formed consolidations have generally been broken and torn away from their original position at the contacts, it is to be expected that at deeper contacts where the magma was not chilled and retained its mobility longer, any differentiation products that might form, would sink or be otherwise moved from their original place of formation and dispersed through magma. Indeed, the numerous patches of varying texture and more basic composition, found everywhere throughout the granite, are believed to be evidence that such action has in fact taken place. It does not, however, appear necessary to assume that differentiation would occur at very deep contacts in the same manner that it would at higher elevations, where the temperature gradient would be much greater where other conditions would likewise be different.

In places, as in the neighborhood of the contacts in Northern Pine Hill, abundant xenoliths of what are quite obviously fragments of the contact phases are very abundant, having been caught in the freezing liquid before they had had time to move, or be moved, far from their original positions. The general distribution of the contact phases through that part of the magma which in time formed the granite is held to account for the presence of the xenoliths generally. In this connection it should be noted that the irregular variation in the composition of the granite, as shown by the microscope and the chemical analyses, is suggestive of movements in a magma not perfectly homogeneous in composition, and this is in keeping with the other evidences above set forth of more or less strong movement in the intruding magma before complete solidification took place. As further bearing on the question of movement, we should note the strong testimony of the broken phenocrysts of the granite-porphyry and of the protoclastic structures in certain portions of the granite (that of the Goldleaf Quarry).

Order of Crystallization in the various phases of the Magma.— The crystallization of the various rock types has been purposely left until they could all be discussed together. The relations of the various

minerals to each other in the granite, as revealed by the microscope, does not in itself lead to any very precise conclusion regarding the order of crystallization.[65] It might be inferred[66] that the feldspar was perhaps first to crystallize, that the quartz and aegirite and perhaps a part of the feldspar (albite) was the last to cease crystallization. Furthermore, the great complexity of the chemical system represented by the granite, its many components and the several complex, isomorphous relationships known to exist between some of them, would render any predictions as to the probable order of crystallization of very difficult, even if we had anything like a full knowledge of the thermal and other data bearing on the question. Owing to the differences in the chemical composition of the coarse-granite and the granite-porphyries etc., and the resultant differences in mineral compositions, we cannot look upon the porphyry as the exact quenched-quickly cooled- equivalent of the granite. However, the figures given show that the differences in mineral composition which would be effective in modifying the order of crystallization are those relating largely to the quartz and feldspar, so that with this in mind we shall find that a comparison of the crystallization in the porphyries with that in the granite leads to a better understanding of the crystallizing process as a whole.

The phenocrysts of the quickly cooled porphyry represent the first crystallizations from the magma. These appear to be quartz and the homogeneous soda-potash-feldspar crystals. If we should assume that the proportions of quartz to feldspar in Vogt's quartz-feldspar eutectic are approximately correct, then the rather close approach in the amounts of these minerals to this proportion might lead us to expect a simultaneous crystallization. The greater proportion of the quartz phenocrysts to those of feldspar in the contact phases of the granite-porphyry found at the higher contact levels, as shown by the Rosival estimates given in columns II and III, p. 243, and the greater resorption of the quartz phenocrysts are probably indicative that the quartz preceded the feldspar in the quickly chilled phases. On the other hand, at deeper levels of the contact, the proportion of the quartz to feldspar phenocrysts is reversed and the amount of the former is relatively small (see column IV, p. 243). Further, if we consider the rhombenporphyry and assume that, in general, the marginal

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[65] In this connection see an interesting paper by N. L. Bowen, Journal of Geology, **20**, No. 5 (July–Aug., 1912), dealing with the order of crystallization in rocks.

[66] See Warren & Palache, op. cit., p. 143–4; also Murgoci, op. cit., p. 137.

differentiates of a magma are richest in those compounds which are the first formed secretions from the magma, and observe that the soda-potash-feldspar is clearly the first mineral to crystallize in this porphyry, we may infer that the feldspar was the first mineral to crystallize, and that the possible appearance of the quartz first, may be due to a reversal of the normal order through supercooling, a condition that did not exist to the same extent at the deeper levels.

In the extreme contact phases at higher levels we find pseudomorphs of what were pretty certainly pyroxene crystals: we have also noted the occurrence of a few phenocrysts of a calcic-iron pyroxene in the granite-porphyry, and that of a more highly sodic variety of pyroxene in the form of small crystals included in the outer parts of the feldspar phenocrysts, as well as in the form of separate crystals. In the rhombenporphyry a calcic-iron pyroxene began to crystallize before the phenocrystalline feldspar had ceased its growth. From these facts we infer that the less sodic pyroxenes began to crystallize shortly after the feldspar.

After a considerable amount of quartz and feldspar with small amounts of pyroxene (possibly aenigmatite) had grown as phenocrysts, there occurred a sharp and clearly marked pause in the crystallization of these constituents. The cause of such a pause is undoubtedly to be found in the supersaturation of the residual liquor, a phenomenon which appears to the writer to be an inevitable incident in the crystallization of a quickly chilled rock magma, such as that of the granite-porphyry unquestionably was. It is clear that before and perhaps during this pause the magma was in movement, for we find fragments of feldspar phenocrysts as well as the broken and irregular ends of the crystals covered by the later growth, itself unbroken. Furthermore, the sealed cracks crossing so many of the phenocrysts extend only to the edge of the original crystal, but not across the later rim. During this pause it is possible that the resorption of the quartz phenocrysts took place. It is also possible that the pyroxene (of more sodic type) continued its growth, and the massive parts of the hornblende began their growth, although their crystallization appears to belong to the second period of crystallizating activity, for they never come normally in contact with the original phenocrystalline feldspar but always lie outside of the later groundmass addition to the feldspars. As we should expect in a supercooled liquid, the crystallization when it was resumed took place about vastly more numerous centers, and so far as can be told there was a practically similtaneous growth of the various minerals. A portion of the feldspars attached themselves as a

parallel growth of microperthite to the already existing feldspar, forming a relatively narrow rim about the larger ones, but a much broader one about the smaller and later phenocrysts. This marginal feldspar includes many quartz and aegirite grains, indicating its contemporaneous age.[67] The first hornblende formed small massive crystals suggesting a slight priority of growth, and as its crystallization progressed, it enclosed poikilitically the quartz and feldspar of the true groundmass, as well as some of the smaller and later feldspar phenocrysts. The greater part of the aegirite, excepting the crystals of distinctly earlier age, is distributed through the groundmass in the form of minute crystals or clusters. The aenigmatite appears to have followed about the same plan of growth as the hornblende.

In the long period during which the granite beneath was solidifying, the porphyry must have remained at a temperature not far below its crystallizing interval, and during this period certain mineral and textural changes took place. The most obvious ones were those connected with the recrystallization of a part of the phenocrystalline feldspar and its albitization, fully described in the earlier part of this paper and to be referred to again. There were doubtless other changes among them, possibly those resulting from some coarsening and modification of the texture by "sammelkrystallization," as it has been termed by F. Rinne.[68]

If we examine the phases of the granite-porphyry which are nearer the granite in the field, we find the same order of progression, but the pause is perhaps less sharply marked, the grain of the groundmass is coarser indicating a longer period of cooling, during which there was time for a more nearly granular type of texture to develop. In the porphyritic phase of the granite, which comes next in order, we find that the pause is almost or quite obliterated and that the groundmass is barely distinguishable from the rest of the rock. Passing now to the coarse-granite, we cannot doubt that the first crystallizations were substantially the same as in the porphyry. The larger amount of quartz relative to the feldspar in the granite suggests that the quartz preceded the feldspar in the beginnings of its crystallization. In

67 In the extreme contact phases the rims about the feldspars are very narrow or impreceptible. This is to be expected, owing to the greater degree of supercooling resulting in a greater impediment to free molecular movement in the highly viscous residual liquors. It should be noted that in some parts of the porphyry a later rim is also found about the quartz phenocrysts, as might be expected.

68 Fortschrift fur Mineralogie, Krystallographie u. Petrographie, **1**, p. 209, et seq.

any case there can be little doubt but that the quartz and feldspar were the first minerals to crystallize. Owing to the very slow cooling (long time period) there was abundant time for a perfect equilibrium to establish itself, no supersaturation ensued, and the minerals continued to grow chiefly by addition to crystals already formed and the crystallization of all these proceeded, accompanied as we shall see by certain transformations, chiefly in the feldspar, throughout the remainder of the main (magmatic) period of crystallization. Succeeding this, and continuous with it, certain changes were effected by the action of late mineralizing vapors or solutions, later growths of albite, aegirite, quartz and zircon being evidence of this. In fact no line can be drawn marking the close of the main period of crystallization, and there is doubtless in all magmas a slight but continuous mineralizing action going on for a long time after the main crystallization has virtually ceased, as the temperature remains relatively high for a long period, and the water, etc. have not been wholly eliminated.

Zircon appears to have grown throughout the entire period of crystallization but to have especially favored the last stages. This agrees with the observations of others on the zircon of similar rocks.[69]

The element of time appears here as the great conditioning factor. A long period of time made the establishment of a relatively perfect equilibrium possible and so smoothed out, as it were, the cooling curves of the magma, and left in the textural relations of the various minerals little or no trace of critical points in the progress of the crystallization.[70]

In the fine-granite, found as the contact phases in the eastern and southeastern parts of the area, we find in the texture good evidence that these contacts were at lower levels of the original contact than were those of the granite-porphyry. The rock is somewhat porphyritic, the phenocrysts being microperthite and quartz. These merge

69 See Murgoci, op. cit., p. 137; also Warren & Palache, op. cit., p. 144.

70 In this connection the writer wishes to direct attention to the discussion of the development of the porphyritic texture given by Professor Crosby in his Blue Hill report (op. cit., pp. 360–1), and in a later paper (On the Origin of Phenocrysts and the Development of the Porphyritic Texture in Igneous Rocks. Amer. Geologist, **25** (May, 1900). Although several statements in this paper are hardly correct in the light of our present knowledge of the laws governing the crystallization of heterogeneous systems, much of his explanation of this texture appears to be substantially in accord with the most recent views on this subject, but does not seem to have been referred to as it deserves. Compare also a paper on the same subject by Professor L. V. Pirsson (Amer. J. Sci., **7** (April, 1889) whose views are discussed by Crosby in the second paper referred to.

into the grain of the rest of the rock, which is like that of the coarse-granite but much finer. We have here probably to deal with a sudden, initial chilling of the magma for a certain distance from the slate contacts, followed, however, by a relatively slow dissipation of the heat when compared with that of the quickly cooled magma at higher levels, which developed the granite-porphyry. We may assume that the sudden, initial chilling caused a sufficient increase in the viscosity to determine more numerous centers of crystallization, while the relatively slow cooling that ensued under the thicker cover of slate permitted the development of an essentially even grained though fine texture. The conditions, like the results, were intermediate between those of the granite-porphyry on the one hand and the coarse-granite on the other. It is also conceivable that the magmatic water and other materials capable of aiding crystallization were retained better in the deeper seated magma than they were in the porphyry-magma, located as it was much nearer the surface.

Differentiation of the Rhombenporphyry.— We may next consider the crystallization of the rhombenporphyry and its bearing on the differentiation of this rock. Here there is no question but that the rhombenfeldspar phenocrysts — homogeneous mixed crystals as we hold them to be — were the first minerals to crystallize. Before the close of the growth of these feldspar phenocrysts the calcic-iron pyroxene began to crystallize. Again we note a pause, marking the close of the phenocrystalline stage of growth, followed by the consolidation of the groundmass about more numerous centers, with a practically simultaneous growth of the minerals and with the addition of a part of the groundmass feldspar — now cryptoperthite or microperthite — to the feldspar crystals already formed. In such a texture there is, in the writer's opinion, proof that the rock was not formed by any process of fractional crystallization. It indicates that the rock was crystallized from an individualized—differentiated—magma of homogeneous composition, at least through such parts as now possess a uniform texture and composition. It is true that the rhombenporphyry as a whole does not possess a perfectly homogeneous composition, and as sodic-pyroxenes and hornblende enter into its composition in some parts, we have doubtless a gradation toward the granite-porphyry. The composition of a part of the xenoliths, obviously fragments broken off from the main masses of this porphyry, show a somewhat further gradation toward the granite-porphyry. The actual contacts between the rhombenporphyry and the other rocks are always sharp, and if there ever was a complete transition between them it is necessary to

assume that those types which were truely gradational in character have now disappeared from sight. It is the writer's opinion, however, that there always existed a sharp or very sudden change from the rhombenporphyry into the other types — a practical discontinuity. A number of similar sudden or sharp contacts between the peripheral differentiates of a magma and the remaining portions have been described from other localities, among the better known examples being those described by Weed & Pirsson in the Shonkin Sag Laccolith, Montana,[71] by Weed & Pirsson in the Square Butte Laccolith, Montana [72] and by Pirsson and Rice at Tripyamid Mountain, N. H.[73] In such cases the evidence all points to a strong diffusion of mineral compounds [74], having an earlier period of formation, toward the cooling surface followed by crystallization of the magma thus formed. Movement of the remaining magma against these differentiated phases does not seem sufficient to fully account for the sudden or even sharp change from one to the other, though as in the present case, it may account for a certain portion of the contacts. Assuming such a diffusion toward the cooling surface to have taken place, may not the process have tended to overrun itself, so to speak, thus bringing about a condition of supersaturation which resulted finally in a more or less sharp pause in the process, a pause analogous to that which has been described as marking the end of the phenocrystalline stage of growth in the case of the feldspar phenocrysts of the porphyries of this area. The result of such a pause is a practically discontinuous contact. It is not the same thing as the formation of immiscible liquid phases in a silicate magma, but the final result is not very different.

The Origin of the Cognate Xenoliths.— The opinion has been expressed that the patches of different texture and more basic composition which occur in the granite and to some extent in the porphyry are in the nature of inclusions of differentiated, peripherial portions of the batholith, and they have been called cognate xenoliths. That some of these xenoliths, as for example those found about the rhombenporphyry on Pine Hill, are nothing but fragments of the rhombenporphyry is perfectly certain, and it may be safely inferred that many others are of the same origin, though they are not so obviously con-

71 Amer. Jour. Sci., **12,** p. 351 (1896).
72 Bull. Geol. Soc. Amer., **6,** pp. 404–5 (1895).
73 Amer. Jour. Sci., **31** (April, May, 1911).
74 In this connection see also Brögger's conclusions to the same effect in a paper on the basic rocks of Gran. Quart. Jour. Geol. Soc., **1**, p. 15 (1894).

nected in the field with the rhombenporphyry. That all of the xenoliths were formed in this way is by no means so certain.

So far as the strongly porphyritic xenoliths are concerned it is important to note that they all exhibit the same characteristics as the granite-porphyry and the rhombenporphyry, in that they have phenocrysts of feldspar, usually of more or less distinct "rhomben" habit, which show a pause in the progress of crystallization followed by a simultaneous crystallization of the groundmass minerals. Furthermore the feldspar phenocrysts in the great majority of cases, and always in the xenoliths of the "rhomben" type of phenocrysts, are, or show positive evidence of having been, either a homogeneous soda-potash feldspar or very fine cryptoperthite, viz.— the same feldspar which is characteristic of the quickly cooled (quenched) phases of the magma. It seems improbable that we should find a small mass of rock possessing a texture indicative of relatively rapid cooling and containing phenocrysts of a type of feldspar, which elsewhere in the field formed only under conditions of rapid cooling, developing such peculiarities *in situ* enclosed in a rock which itself is typically granitoid and developed under conditions of slow cooling. It might be contended that these xenoliths have developed about one or more crystals of the feldspar, acting as nuclei, by some process of fractional crystallization, and that the rim of later growth was due to a growth of larger crystals at the expense of smaller ones during the period in which the material was surrounded by the hot, granite magma. The presence of poikilitically developed hornblende perhaps might also be cited to support this contention. It appears, however, to the writer that in such a case the same action of the hot magma would pretty certainly have effected a recrystallization of the feldspar phenocrysts since, as we have shown, these are very easily changed, and such changes have not been observed to be common in the feldspar phenocrysts of this type of xenolith; nor does it seem likely that so perfect a reproduction of the normal porphyritic texture could result. Furthermore, a process of gradual accumulation from the surrounding magma could hardly be expected to result here in sharp contacts, which are a characteristic of all of the xenoliths. The rounded, irregular and indented contacts of the xenoliths with the enclosing granite, so beautifully exposed on the glaciated ledge beside the railroad track east of Pine Hill, and the flow structures sometimes observed in them, suggest simply a softening and moulding of the xenolithic masses by the hot granite magma. It might also be contended that they represent consolidated liquid segregations formed *in situ* and that their finer tex-

ture was due to their more basic (than the granite) character, or to a tendency of the earlier formed minerals to form smaller crystals.[75] The same objection raised above, that the feldspar phenocrysts are not recrystallized, would operate strongly against this view, nor is there any evidence that because of a more basic or different chemical composition there should result such a texture as that described: nor is it the earlier formed minerals that are the smaller in size, but exactly the reverse. In this whole group of xenoliths (those with a marked porphyritic texture) there is little, if any, evidence that there has been any addition of material from the enclosing magma, and little, that there has even been any noteworthy recrystallization of the xenolith since its first formation.

In the case of the feebly or non-porphyritic xenoliths, particularly those of finely granitic texture, there is less positive evidence as to their origin. It is true that many of them contain phenocrysts of microperthite which show traces of an earlier formed core. But this is, in character, like the margin. It may be that this type represents spots in the granite which for some unknown reason developed a finer texture. But why they should have sharp contacts or why, in the case of those so near the granite in chemical composition as to possess, at best, but very slight differences effective in modifying the texture, they should show a contrasted texture, is not at all clear. It has been pointed out that, allowing for possible changes in chemical composition effected perhaps by the enclosing granite magma, the xenoliths as a whole correspond rather closely, and in part almost exactly, to the various types of rock found as peripheral phases of the batholith. For reasons above set forth, the writer believes that the porphyritic xenoliths are simply fragments of the peripheral phases of the batholith, broken up and more or less moulded in form by movements in the hot magma, and that these fragments have in part sunk in the magma or been moved from their original positions by the same movements. He is also strongly inclined to believe that all of the patches of contrasted texture are the result of the same process.

The above statements regarding the origin of the xenoliths appear to be in substantial accord with the views of Professor Crosby. Inasmuch as he relied on Dr. White's descriptions of their microscopic characters some of his statements regarding them differ materially from the writer's. We are, however, agreed that the porphyritic texture is a plain indication that the crystallization followed, and did

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75 See Harker, op. cit., p. 348.

not precede differentiation.[76] Crosby's final statement regarding their origin is as follows [77]: — ". . . . segregation on a large scale and subsequent crystallization developed a continuous zone of basic-porphyry: and that as the energy of the process diminished, or where it was primarily weak, it became more or less localized, developing isolated segregations which were subject to various accidents — distortion, cracking and crowding — during the gradual stiffening of the enclosing magma." The writer is disposed to insist that the evidence, as above given, shows that the segregation referred to by Crosby was confined to the immediate contacts and that it did not form small localized masses (the size of the present xenoliths) in the magma at points distant from the contact.

The Relations between the Soda and Potash Feldspars.— In the descriptive part of this paper it has been noted that the feldspar which occurs in the form of phenocrysts in the porphyries, when unaltered, is a soda-orthoclase (?) — or a very fine cryptoperthite. The phenocrysts consist centrally of a homogeneous material or a very fine (almost homogeneous) cryptoperthite, but toward the margins they become more distinctly perthitic though the structure is still very fine. In the groundmass of the rhombenporphyry and in the later rims of groundmass age about the phenocrysts, we have cryptoperthite or coarser microperthite; in the granite-porphyry the rims about the phenocrysts are of microperthite as are also the small crystals in the groundmass. In the granites, on the other hand, the feldspar is throughout a strongly developed and fairly coarse microcline-microperthite, with a very subordinate amount of separately crystallized albite, and this is located about the ends or sides of the microperthite crystals, usually as a continuation of the albite within the body of the crystal.

Recently J. H. L. Vogt [78] in an elaborate paper, has developed the view that the anorthoclase — cryptoperthite — feldspars are eutectic mixtures and proposes to designate them as "eutectic feldspars." As the result of a statistical study of the available chemical analyses of feldspars and the rocks in which they occur, he has computed that the eutectic mixture lies between the limits 40–44 Or: 60–56 Ab + An; that the mixed crystal phases forming the eutectic are about Or, 12%: Ab + An 88%, and 72% Or: 28% Ab + An. That is, he believes

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[76] op. cit., p. 372.
[77] op. cit., p. 373.
[78] Tschermak's Mineral. u. Petrog. Mitt., **24**, No. 6 (1906).

that mixtures of potash-feldspar and plagioclase belong to type V of Roosebooms'[79] classification of mixed crystals; viz.— they have a limited miscibility in the crystalline condition with a eutectic point between the two resulting types of mixed crystals. His figures are admittedly only approximations and future investigation will doubtless modify them in some particulars, but nevertheless his views are to the highest degree suggestive and important. At temperatures lower than that at which the anorthoclase or cryptoperthite crystallizes, some diminution of the solubility of the one feldspar in the other in the mixed crystals, would probably result connected, probably, with a transition to another crystalline modification in the case of at least one component, and a transformation, an unmixing (*entmischung*), in the solid condition would then take place. The perthite or microperthite which might in such case result, would consist of a potash feldspar containing less Ab or Ab + An than it would at higher temperatures, and a plagioclase member, likewise poorer in Or. Vogt estimates that the potash member would contain in such cases 10–15% of Ab or Ab + An. That the perthitic intergrowth is due in general to an unmixing of an earlier existing homogeneous mixture, has also been entertained by several other petrographers,[80] although none have put their ideas into such definite form as has Vogt.

It appears to be pretty well established that there are all gradations between microperthite and cryptoperthite; that there is a truly gradual gradation into a perfectly homogeneous soda-potash feldspar is not so certain. It may be entirely correct to look upon the homogeneous anorthoclase as being a crystallized eutectic mixture, but the writer is led to go somewhat further and suggest that the apparently homogeneous mixtures may be a true mixed crystal belonging to Type 1 of Rooseboom, viz.— the two feldspars are miscible in all proportions in the solid crystalline state.[81] It may be noted that anorthoclase presents certain peculiarities that perhaps suggest a mixed crystal. It is a familiar fact that its crystals frequently show a division into fields when examined under crossed nicols, in fact, these may be visible megascopically. This phenomenon is common in mixed crystals such as the garnets and alums. Again the crystalline

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79 Zeitschr. f. Phys. Chem., **30** (1897).

80 Rosenbusch, F. Becke and others.

81 Since this was written a paper by Dr. E. Dittler (T. M. P. M., Nos. IV–V, **31**, pp. 511–22, 1912) has come to the author's attention, in which experimental evidence is given to the effect that the alkalic feldspars form mixtures belonging to type 111 of Rooseboom's classification; viz.— a continuous line of mixed crystals tending toward a minimum freezing point.

habit of the anorthoclase commonly differs from ordinary feldspars. The crystals are often curiously distorted, acute terminations being common. These may be due to the physical conditions of the solution under which they grew, but one cannot but recall that such abnormalities are characteristic of certain mixed-crystals among laboratory salts.

There seems, however, to be more direct evidence of the complete isomorphism of the soda and potash feldspars. P. L. Barbier and A. Prost [82] of Lyon, France, have recently described monoclinic feldspars in which the soda is present in a molecularly greater amount than the potash. This has been confirmed by Dr. W. T. Schaller [83] of Washington, who has suggested for the new monoclinic modification of soda feldspar, thus shown to exist, the name "Barbierite" in honor of its discoverer. F. Angel [84] has also described a "Soda bearing, monoclinic sanidine containing 4.95% Na_2O and 6.75% K_2O from Mitrowitza. Although anorthoclase appears to be triclinic at ordinary temperatures it is worthy of note that according to Forstner [85] it becomes monoclinic at higher temperatures.

It appears to the writer that at the temperature of crystallization we may assume that the potash and soda-feldspars form mixed-crystals of Type 1, and that this condition of equilibrium continues to hold for an interval, probably a short one, below this temperature. With lowering temperatures both of the components may pass through an inversion point, going over into other crystalline modifications, albite and microcline. This produces a radical change in the equilibrium of the system, with the result that there is an unmixing of the original mixed-crystal phase, and the formation of two new mixed-crystal phases having a eutectic point between them — that is, they pass from Type 1 of Roosebooms' to Type V. One of these phases is albite, or a highly sodic feldspar of the albite type, holding still in solution some of the other component, and the other is a microcline likewise with some albite dissolved in it. If this be so, it would appear that the alkali feldspars exist in two modifications each, an α and a β form. Vogt [86] has discussed this question for microcline and arrived at the conclusion that orthoclase and microcline stand to each other in the relation of an α and β form, and he compares the polysynthetic

82 Bull. Soc. Chem., p. 111 (1908).
83 Bull. No. 509, U. S. Geological Survey (1912).
84 Neues Jahrb. fur Min., Biel-Band, **30** (1910).
85 Zeit. f. Kryst., etc., **9**, p. 333 (1884).
86 op. cit., p. 540.

twinning structure of the latter with that of the well known case of leucite. It is true, so far as the writer can ascertain, that the potash member of such microperthites, where this has been determined carefully, is microcline either with the usual gitter structure, or with the albite twinning alone, or even without twinning.

The theory above put forth does not contradict the conclusion of Vogt that many, perhaps most microperthites and cryptoperthites are essentially eutectic mixtures. It supplements it by way of adding something to the theory of feldspar mixtures so far as the alkalic members are concerned, and it is believed may lead to somewhat better understanding of their relations in igneous rocks generally. The approximation to constancy in the composition of the cryptoperthite and microperthite feldspars as shown by Vogt, is a strong argument in favor of their being eutectic in nature. Their peculiar structure is also favorable to this view. For, if we reason from the analogy of the well known eutectic structures in alloys and laboratory salts in which one of the characteristics is an intimate mechanical or crystallographic mixture of the two phases forming the eutectic, we should expect to find in feldspar mixtures, which are of nearly or exactly eutectic composition, a corresponding tendency to form an intimate and curious intergrowth. In view of the well recognized sluggishness associated with transformations in the solid state, we should expect that the unmixing at a transition point, such as the one suggested above, would in many, perhaps most cases be more or less incomplete, and in mixtures which originally departed more or less widely from eutectic proportions, it is probable that the resulting crypto- or microperthite would, owing to the incomplete separation of the two phases, be only an approximate eutectic ("anchi-eutectic" of Vogt). To the sluggishness of transformations in the solid state must be added in the case of the feldspars a further, and doubtless considerable, impediment to the progress of the readjustment caused by the extraordinarily viscous character of the feldspar substance. This may be inferred from the thermal properties of the feldspars as revealed by the brilliant work of Dr. A. L. Day [87] and his associates at the Geophysical Laboratory in Washington, D. C. On account of their peculiar thermal properties it is to be expected that except under the most favorable conditions, critical points on their cooling curves will be readily passed by through supercooling, and that we should rather speak of critical intervals than points. For the same reasons, while

[87] The Thermal Properties of the Feldspars, Carnegie Institution, Washington, D. C., (1905), and American Journal of Science, **14** (Feb., 1905).

the feldspars doubtless tend to form a eutectic mixture theoretically, it is highly probable that in the actual crystallization this tendency may often fail of complete realization, and that Vogt's term "anchi" — approximate — may be appropriately applied to the intergrowths of the two feldspars as eutectics, and to the two mixed-crystal phases as well.

The phenocrysts of lavas and of the contact phases of an intrusive igneous mass, like the one under consideration in the present paper, grow with relative rapidity and are then frozen in the quickly consolidated groundmass. These are precisely the conditions which are favorable to the preservation of the crystal in the condition in which it first formed, even after the temperature falls below a possible transition point, provided the tendency to readjustment, which would normally ensue, is not very strong, and the actual change itself is hindered sufficiently by the molecular immobility of the now solid crystal as well as by the relatively rigid surroundings. In other words, a phase, stable at higher temperatures, is caught by the quenching of the magma and rendered relatively stable at lower temperatures. If a crystal in a metastable condition be long held at a temperature, at or below, its transition point, or is acted upon at relatively high temperatures by a liquid or vapor, especially if the stable phase is present, it will, as is well known, generally go over to the stable phase. Precisely this thing appears to have occurred in the case of the feldspar phenocrysts of the Blue Hill porphyries. Parts, perhaps almost the entire phenocryst of feldspar, will be, so far as the microscope shows, of entirely homogeneous structure, but through this, streaks and patches are found, of cryptoperthite or very fine microperthite. As we approach the margin of the crystal the same thing is observed, and the crystal for an indefinite, short distance from the margin consists of a perthitic intergrowth. The streaks and patches in the inner parts of the crystal are believed to be due to an *unmixing* under the action of long continued heat, accompanied probably by the action of heated vapors or solutions permeating the rock. The marginal microperthite may be due to the same cause, but it seems more probable that at the time when this grew the temperature had fallen to a point below the transition interval, and the two phases separated more or less completely, forming the crypto- or microperthite; the cryptoperthite here, and in general, representing a structure resulting under conditions less favorable to a *free unmixing* than the microperthite. It is to be noted that the generally widespread and clearly marked recrystallization of the phenocrysts in the porphyries is, it is believed,

an evidence of the generally unstable condition of the feldspar phenocrysts as first formed from the magma. As still further bearing on this question we may note that the smaller and later formed phenocrysts are largely microperthite, and that the feldpsar which developed in the groundmass of the porphyries, in part attaching itself to the older phenocrysts, is all microperthite. This part of the feldspar content of the rock obviously solidified at lower temperatures than the phenocrysts, and, if our theory is correct, formed the region lying below the transition interval.

When we come to the coarse-granite we find that all of the feldspar is a relatively coarse microperthite. In that part of the magma which eventually formed the granite a very long cooling period obtained, during which there would be ample opportunity for the establishment of more perfect equilibria in general. The mixed crystals of soda-potash feldspar which first formed would pass through the transition interval, but, in sharp contrast to conditions obtaining in the porphyry magma, there would be no supercooling, and enough time for the readjustments to take place. The new phases did not move far, but rather withdrew from each other, and being still closely similar crystallographically, finally took up the relative positions in which we now find them; viz.— they formed an intimate, crystallographic intergrowth.

Regarding the composition of the soda-potash-feldspar eutectic, there is still, as is to be expected, both on account of the peculiar physical properties of the feldspars alluded to above, as well as on account of the character of the available evidence bearing on the question, much uncertainty. The approximate compositions of the feldspars, as calculated from the analyses of the Quincy-Blue Hill rocks, show some divergence from the figures worked out by Vogt. The limiting values for the concentrations of one feldspar in the other, as given by that author, appear to the writer as being open to some question. In the present rocks the sodic member, so far as can be told, appears to be a very pure albite, likewise the potash member seems to be a highly potassic microcline. It would appear, if the writer's deductions are correct, that the concentrations of the two feldspars in the mixed crystal phases may be lower, at least for the highly alkalic feldspars, than is indicated by the figures of Vogt. That the eutectic composition lies in the general region indicated by him appears probable. It is of course true that Vogt's conclusions include more calcic plagioclases than are concerned in the present case, and it seems not improbable that with the presence of more of the

lime feldspar molecule, different conditions of equilibrium come into play, and that for a certain concentration of anorthite, complete crystal miscibility may not obtain, but only partial miscibility, and that such feldspar systems belong to type V only of Roosebooms' classification.

The unmixing of a previously homogeneous mixture is believed to offer also an explanation of the occurrence of albite about the margins of the microperthite grains in the granite, and also in part, of the presence of strongly marked albitization of some of the original feldspar in the porphyries. Assuming that the albite present in the soda-potash mixed-crystal was in excess of the eutectic proportions stable at lower temperatures, we should expect that, in the process of readjustment which would take below the inversion point above postulated, that some of the albite phase would be set free and that it would be forced out upon the final crystallization of the microperthite. Much of it would be expected to attach itself directly to the albite exposed along the margins of the microperthite crystals, while some of it would grow alongside as separate crystals or even migrate to more distant parts of the rock. The same thing would happen in the case of the feldspar growing in the groundmass of the porphyry, but there would be present the metastable, earlier formed phenocrysts, which would be readily effected by the liquors rich in albite, thus producing the albitization described as so commonly observed in the porphyries. This theory relieves us of the necessity of calling upon the underlying magma to supply albite bearing solutions in the considerable amount necessary to furnish all of the later albite in the porphyry. It does not, however, by any means exclude the probability, that the underlying, crystallizing magma has furnished some part of the albite.

Development of Microliths in the Feldspar. — The writer has expressed the opinion in this paper and elsewhere [88], that the microliths of aegirite found so abundantly in the feldspar of the granite were not products of earlier crystallization, but were of later origin. During the readjustments in the feldspar to meet changed conditions of equilibrium have we not a most favorable time for the introduction of those minute crystallizations of a mineral which is known to have been growing during the later period of crystallizing activity? During the readjustments within the feldspar, would we not have the degree of

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88 Warren & Palache. Pegmatites of the Quincy Granite, etc., op. cit. p. 145.

molecular mobility and openness of structure, if we may use such a term in this connection, to favor the introduction of extraneous material, aegirite, etc? Does not also the presence of the innumerable, minute vesicles in part, at least, date from this period of change? It is of course possible that the aegirite, etc. represents material that was originally held in solution in the feldspar material, and that it separated out during the unmixing of the original crystal. No microliths of aegirite nor of any other mineral appear in the homogeneous parts of the phenocrysts in the granite-porphyry, and this alone is believed to be very strong evidence that they made their appearance during the unmixing and probably by introduction from sources outside the feldspar crystals themselves. This has, of course, no connection with those microlithes and larger crystal grains, such as the riebeckite, which are connected with later alterations in the rocks.

In this connection it is perhaps worth noting that the pyroxene and amphiboles may also undergo transformations of which we have as yet no definite information.

Summary.

The alkaline granitic magma of Quincy and the Blue Hills was intruded as a small batholithic mass, later than the middle cambrian, but earlier than the late carboniferous period. The method of intrusion is believed to have been one of "stoping." The magma as a whole is believed to have stoped its way upward to a relatively high elevation in the pre-existing formations, and a considerable portion of it reached a position very near the surface. As a result, the upper portions consolidated to highly vitreous rocks, while somewhat lower portions formed thick masses of porphyritic, crystalline rocks,—quartz-feldspar and granite-porphyries. The extreme upper portions were perhaps more siliceous and richer in volatile constituents, which in large part may have escaped; lower portions consolidated without substantial differentiation or change. As an incident to intrusion, the earlier consolidated portions were much broken, engulfed in the magma beneath, and against these, as against the original contacts, the residual magma consolidated with a varying degree of chilling, according to position. At considerably lower contact levels now exposed in the eastern part of the field, the magma consolidated with a marginal zone of fine-granite as the contact phase. Here also the first formed rock was intruded by, broken up, and to some extent

engulfed in the magma beneath. Under the thick cover of porphyries acting as an effective insulator, as well as along the deeper original contacts, the remaining magma cooled with sufficient slowness to permit of the development of a medium coarse, even grained rock, the granite.

Locally, against deep projections of slate, as well as to a small degree under its own porphyry cover, the magma differentiated with the formation of a relatively basic phase, the rhombenporphyry. Some part of this basic differentiate still remains in place against the slates, but considerable portions of it were broken up, and together with fragments of the other contact phases, were scattered by sinking, and movements in the magma. Many of these were eventually frozen in the magma, particularly near their original places of formation, and now form the cognate xenoliths (knots) so abundant in the granite.

Long continued erosion has removed nearly all of the original slates etc. invaded by the magma, together with some portion of the first formed marginal cover of igneous rocks. Faulting and elevation of the mass, particularly along its northern edge, has brought up into the plane of erosion a portion of the original deep seated slate-granite contacts.

Owing probably to the small capacity possessed by the magma for differentiation, combined with the rapid refrigeration of a great part of the magma, no complementary dike phenomena or other intrusions of complementary nature were developed, and are, in striking contrast to many other batholithic intrusions of granitic rocks, absent from this area.

In the case of the rhombenporphyry and the cognate xenoliths derived from it, it is held that their crystallization followed differentiation, and that the process of differentiation was one of diffusion of compounds, which were normally the first to crystallize from the magma, toward the cooling surface. It is held that while a part of the sharp contacts between this basic phase and the granite-porphyry and granite are due to mechanical causes (breaking and movements in the magma) there was originally a practical discontinuity — sharp or very sudden change — between the rhombenporphyry and the main magma.

Chemically the magma as a whole is characterized by high silica, high alkalies, relatively high iron and by very low lime and magnesia. The alkalies are about equal, the potash slightly predominating in amount, but molecularly less important than the soda. Chief accessory constituents are zirconium, titanium and fluorine.

The feldspar is substantially a mixture of soda and potash molecules. In the phenocrysts of the porphyries much of it appears as a homogeneous mixture of the two. Irregularly through parts of the phenocrysts, and toward their margins, cryptoperthite or microperthite appears. A later growth of fine microperthite attached to the phenocrysts, but of groundmass age, occurs. The feldspar of the groundmass is microperthite. In the granites, the feldspar is substantially all microperthite, a little free albite occurring about the ends and sides of the crystals. The microperthite throughout, so far as can be told, is a microcline-albite microperthite. Later changes of a deep-seated character have profoundly altered much of the phenocrystalline feldspar of the porphyries, either recrystallizing it to an aggregate of albite and microcline, or in part replacing it with albite. Similar replacements have occurred to some extent in the granitic feldspar.

The predominant dark silicate is hornblende, of which two varieties appear. One of these is riebeckite or a closely allied type, the other appears to be closely related to the cataphorites. Both are generally present: on the whole the riebeckitic variety clearly predominates and hence the rocks have been characterized as riebeckitic. The predominant pyroxene, by a wide margin, is aegirite. In the most basic member of the rock-series a variety of pyroxene rich in the calcium-ferrous iron molecule appears. This is found to a very small extent in the more siliceous porphyries but gives place to a more highly sodic type, which also occurs in the granites to a small extent. The rare mineral aenigmatite occurs in the granite and in the granite-porphyry.

The predominant molecules in the hornblendes are: — $Na_2Fe_2Si_4O_{12}$, $(R'_2,R'')\ Fe_2Si_4O_{12}$ — where R' is soda with small amounts of fluorine and hydroxyl, and R'', ferrous iron chiefly — and $Fe_4Si_4O_{12}$: In the pyroxenes $Na_2Fe_2Si_4O_{12}$ strongly predominates but $Ca\ Fe\ Si_2O_6$ is often present. The conditions determining the formation of these minerals is very obscure, but slight variations in the concentrations of the constituent oxides present, local variations in the amounts of mineralizers, particularly fluorine, and the rate of cooling, are doubtless the most important factors concerned.

The hornblendes are readily effected by alteration, and change first to a deep-blue, riebeckitic or crocidolitic variety and eventually change to magnetite and other iron oxides. The aegirite is less readily altered.

Alteration, deep-seated or superficial has not much effected the granites, except locally, but the porphyritic rocks have suffered more

generally, so much so, that their original structures are often profoundly changed.

Quartz and a soda-potash feldspar (mixed crystal) appear as the first crystallizations from the porphyry magma, followed closely by the less sodic-pyroxenes. It is thought, however, that the feldspar was the first crystalline phase to form normally, followed quickly by the quartz and pyroxene. These were followed by the other minerals. It is inferred that in the granite the order of crystallization was substantially the same as that of the granite-porphyry. In the porphyries there was a sharply marked pause closing the phenocrystalline stage of growth, due, it is believed, to supersaturation, after which crystallization was resumed, but about vastly more numerous centers, the various minerals continuing to grow almost or quite simultaneously, in part attaching themselves to the earlier formed crystals, but largely forming a fined grained groundmass, in part with a poikilitic fabric. In the porphyritic phase of the granite, into which the granite-porphyry passes, the pause in the progress of the crystallization was less marked, and in the normal granite it did not occur, owing to the more perfect conditions of equilibrium conditioned by very slow cooling. The later crystallizations added themselves to the crystals already present, and thus obliterated all distinction between phenocrysts and groundmass.

It is held that the granite-porphyry represents substantially the composition of the magma as intruded, and that beneath this protecting cover the remaining magma was able to differentiate to a small extent forming a more basic phase, the rhombenporphyry, itself becoming in consequence more siliceous. Assuming that by this differentiation the granite moves toward a eutectic composition, which is by no means a necessary or certain procedure, it is pointed out that the proportions of quartz to the feldspars departs quite widely from the granite eutectic proportions as estimated by Vogt. In fact the proportions of these minerals in the granite-porphyry is nearer to Vogt's eutectic ratio than are those of the granite, which appears to be a variation in the wrong direction to agree with his theory. The effect of the presence of the sodic-iron silicates on the composition of a possible eutectic is not yet determinable, and in any case, the composition of the granite eutectic appears to be a very open question.

It is suggested that the potash and highly sodic-feldspars may first crystallize as homogeneous mixed-crystals (type I, of Rooseboom) and at somewhat lower temperatures pass though a transition point, or interval, becoming then only partially miscible in the solid state,

with a eutectic point between the two resulting types of mixed crystals, albite and microcline (type V of Rooseboom). The homogeneous feldspar phenocrysts, or such parts of them as are still homogeneous, represent the first formed type caught in the rapidly chilled magma, and now exist in an unstable condition. The cryptoperthite and microperthite generally throughout the porphyries, and granites, are regarded as the result of an unmixing below the transition point or interval, and probably represent an approximate eutectic mixture, or a true eutectic, provided that the readjustment had time to complete itself. It is suggested that the prominence of the albite phase about the margins of the granitic microperthite crystals, and elsewhere in the rocks as an apparently late crystallization, is due, in part at least, to the excess over eutectic proportions of that constituent in the original mixed-crystals, and that it was set free during the unmixing and thus became active during the late stages of crystallization. This period of unmixing was probably that during which the aegirite microliths, etc. were introduced into the feldspar of the granite. This and the albite crystallizations were doubtless aided by the last liquids (mineralizers) of the magma. It is thought that, at least for mixtures containing as in the present case, a highly sodic member, the concentrations of one feldspar in the other in the two phases of the eutectic mixture, are probably not as great as those calculated by Vogt, and that the true eutectic proportions may depart somewhat from the value deduced by him, but that this value is not much in error.

It is pointed out that following the transformations which are believed to have taken place during the late magmatic period, there were further and more or less profound alterations of a deep-seated character in the minerals of the porphyries, and to a less extent in the granites. Subsequent surface alteration has, in many localities, resulted in still further changes chiefly affecting the iron-bearing silicates.

The characteristics of these rocks show a close analogy in many respects to those described for other intrusions of riebeckite-aegirite granites, and in this respect are in general agreement with the generalizations of Murgoci regarding this class of rocks.

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PLATE 1.

Fig. I.— Granite-Porphyry, Rattlesnake Hill, Blue Hills. At the bottom on the right, is a pyroxene crystal surrounded by poikolitic hornblende enclosing groundmass grains; above appears a cluster of aenigmatite grains; on the left, below, is a cross-section of a pyroxene crystal with a small slightly darker margin of aegirite; above is a massive hornblende becoming poikolitic outwardly and then showing enclosed groundmass grains. With the exception of a small phenocrysts of feldspar, barely seen just above the center, the rest of the section is all groundmass in which tiny microliths of aegirite can be seen.

Photomicrograph, plane light. Magnification about 15 diams.

Fig. II.— Granite-Porphyry, Sassoman Pass, Blue Hills. On the right is shown the edge of a large phenocryst of nearly homogeneous soda-potash feldspar terminated by a sharply marked line outside of which is a narrow margin of microperthite enclosing tiny groundmass crystals; near the bottom is a small phenocryst of feldspar with a relatively broad, later rim; the rim shows a delicate perthite structure which is also developed for a short distance within the inner and earlier formed part. A similar phenocryst appears at the top of the section. At the extreme lower side is seen a small phenocryst of relatively late age enveloped by a relatively very wide rim of later age. In this rim are minute enclosures of groundmass grains. The dark part of the field is hornblende, poikolitically enclosing feldspar (microperthite) and quartz crystals.

Microphotograph, plane light. Magnification about 25 diams.

Figure III.— Granite-Porphyry, Rattlesnake Hill, Blue Hills. This shows a phenocryst of soda-potash feldspar surrounded by a narrow rim of later microperthite enclosing groundmass grains. There is a faint perthite structure developed in the inside portion of the phenocrysts next the rim but this is very indistinctly shown with the magnification used. The phenocryst is crossed by streaks representing cracks sealed with albite. A part of the body of the crystal has suffered a recrystallization, shown as flower-like areas.

Microphotograph, crossed nicols. Magnification about 25 diams.

Fig. IVa.— Granite-Porphyry, Chicatawbut Hill, Blue Hills. This shows one end of a largely recrystallized feldspar phenocryst. The boundary of the phenocryst is marked by a sharp line outside of which is a rim of later groundmass age. Old cracks, now sealed with albite, and having a deposit of minute aegirite microliths on either side of them cross the phenocryst.

Microphotograph, plane polarized light. Magnification about 25 diams.

Fig. IVb.— Same as fig. IVa, but with crossed nicols. Nearly the whole interior of the phenocryst is seen to be recrystallized to a fine aggregate of feldspar-microcline and albite. A good part of the crystals stand normal to the direction of the albite streaks which are seen to run into the marginal

parts of the original feldspar substance, and these have not yet suffered recrystallization, having been of more stable composition than the interior.

Fig. V.— Altered granite-porphyry, between Hemingway and Hancock Hills, Blue Hills. This shows the remnants of two feldspar phenocrysts. All that remains of the original crystals is a part of the margin. The white streaks of albite, which mark the position of cracks in the original crystal, remain (see figs. III and IV). Between these is now a mass of albite and microcline grains which are scarcely distinguishable from the surrounding groundmass. This illustrates an extreme stage in the destruction of the feldspar phenocrysts. The groundmass still shows most of the original aegirite, but the hornblende has suffered much modification.

Microphotograph, crossed nicols. Magnification about 25 diams.

PLATE 2.

Fig. VI.— Granite-porphyry from about 20 ft. back from the contact, east of summit Pine Hill, West Quincy. Shows a feldspar phenocryst crossed by streaks of albite and recrystallized to a curiously mottled microperthite. About the end of the crystal is seen a micrographic intergrowth of quartz and feldspar. The groundmass is here much coarser in grain than in the porphyry of the Rattlesnake Hill type and the grain is fast approaching that of the granite into which this rock passes within about twenty feet.

Microphotograph, crossed nicols. Magnification about 25 diameters.

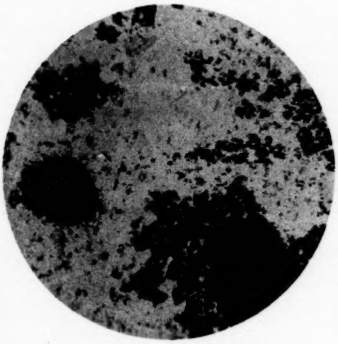
Fig. VIIa.— Quartz-feldspar-porphyry, from near the top of Hemingway Hill, Blue Hills. This shows the greater part of a feldspar phenocryst which has undergone a partial and unusual alteration. Considerable portions of it are still a perfectly homogeneous, but about its margins, also along the edges of a break which crosses it, it has been replaced by a narrow band of normally orientated lath-like crystals of albite and microcline. A large part of the interior has been changed to small areas of microperthite of curious pattern (see Figure VIIb). The groundmass has been forced in along the break referred to.

Microphotograph, crossed nicols. Magnification about 25 diams.

Fig. VIIb.— Same section as Figure VIIa. Shows a feldspar phenocryst to some extent broken and entirely changed to a curious aggregate of small microperthite areas. The structure of these areas is irregular and slightly divergent giving the effect of a curious and beautiful tracery.

Microphotograph, crossed nicols. Magnification about 25 diams.

Fig. VIIIa.— Rhombenporphyry Xenolith, Pine Hill Area, West Quincy. Shows a characteristic phenocryst of soda-orthoclase (anorthoclase?) The shape of the crystal is characteristic of much of the feldspar in the rhombenporphyry as a whole, likewise the minute rod-like pyroxene microliths, located just outside the sharply marked boundary but lying in a band of feldspar



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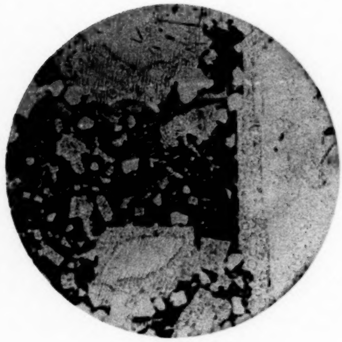

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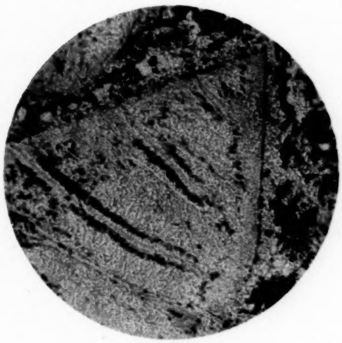

IVa

IVb

V

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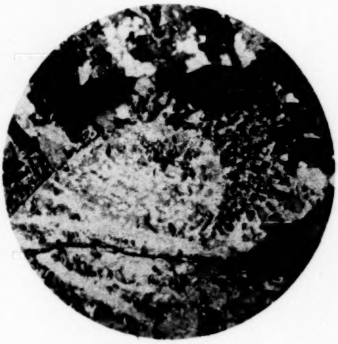
substance attached to the phenocryst. The groundmass consists of microperthite and pyroxene with some hornblende.

Microphotograph, plane light. Magnification about 15 diams.

Fig. VIIIb.— Same crystal as in Figure VIIIa but with crossed nicols. The attached border of microperthite of groundmass age is well shown.

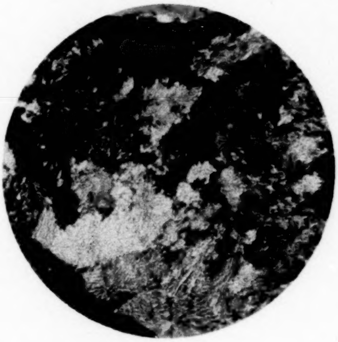
Fig. IX.— Rhombenporphyry, Pine Hill Area, West Quincy. This shows a composite feldspar phenocryst, the acutely terminated points of the crystals pointing the same way. The development of minute pyroxene microliths in the marginal growth of feldspar just outside the boundary of the original phenocryst is well shown.

Microphotograph, plane light. Magnification about 15 diams.



VI

VIIa



VIIb

VIIIa

VIIIb

IX

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